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Assessment of the effectiveness of reported Water Framework Directive Programmes of Measures

Part III – JRC Pressure Indicators v.2.0: nutrients, urban runoff, flow regime and hydromorphological alteration

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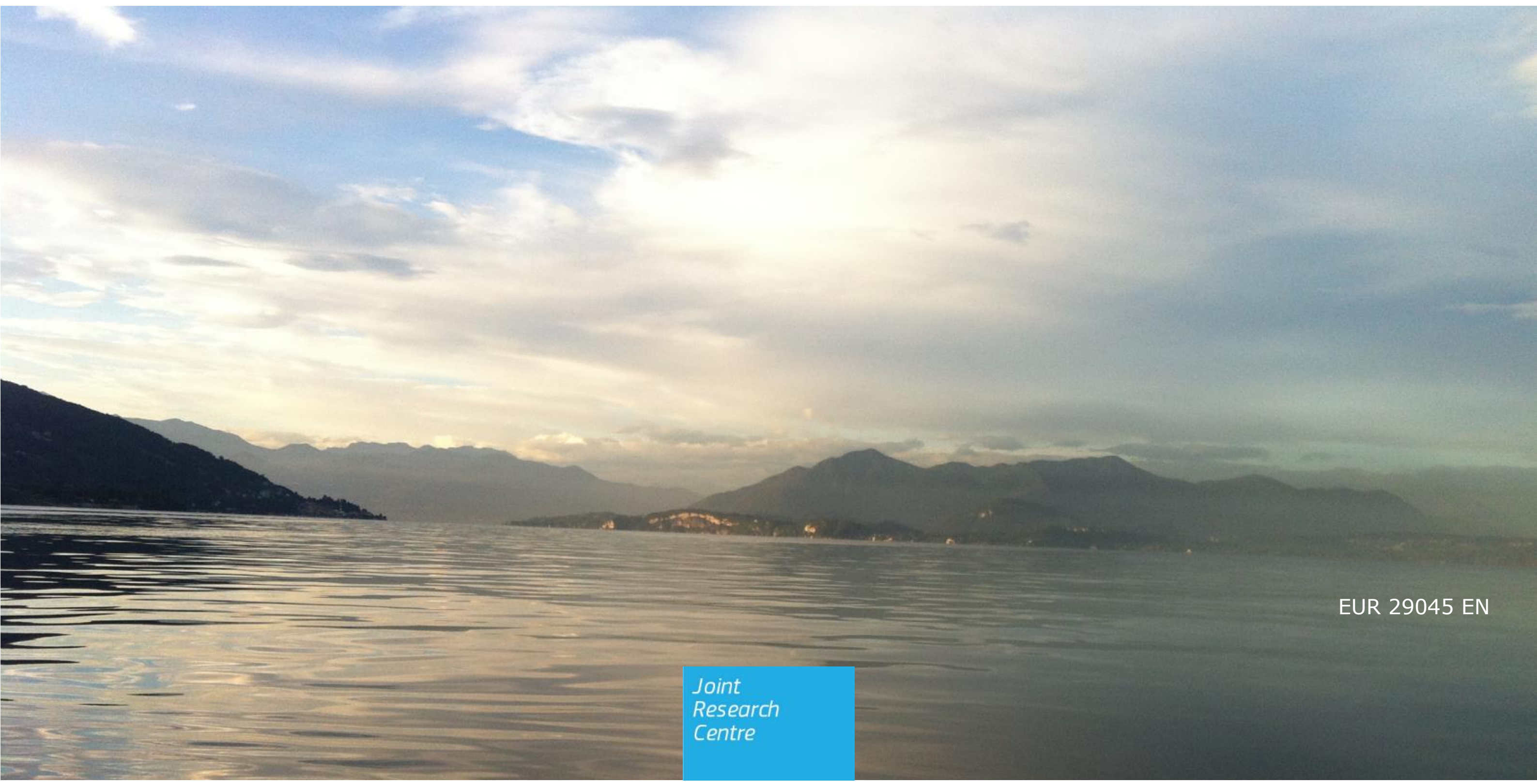

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Abstract

This report illustrates a system of indicators (called JRC Water Pressure Indicators) providing a consistent picture of human pressures on water bodies at European scale, to be compared with pressure and status information reported by Member States under the Water Framework Directive 60/2000/EC. The indicators represent "version 2.0" of a "version 1.0" published before[1]. This "version 2.0" was introduced in Pistocchi et al. (2017)[2] and includes nutrients, urban runoff, hydromorphological and flow regime alterations, and in particular:

- an updated GREEN model setup for estimating nitrogen and phosphorus load to European surface waters;
- the updated indicators of morphological alteration of floodplains produced with the Copernicus riparian zones layer[3];
- the indicators of flow regime perturbation and river continuity disruption, due to dams and other stream barriers in Europe, computed on the basis of a new dataset compiled by the JRC;
- the indicators of flow regime alteration due to abstractions, using estimates of demand for irrigation, livestock, domestic and industrial water use and cooling of energy production plants, and information on natural water availability simulated with a calibrated LISFLOOD model.

A relevant change from version 1.0 to version 2.0 is the spatial support of the indicators. While in version 1.0 the indicators were computed at the level of HydroEurope (HE1) subbasins, i.e. polygons of an average size of 180 km2, or on grids of 5 km or 1 km resolution (see Pistocchi et al., 2015, for details) and aggregated at the river basin district (RBD) scale, in version 2.0 all indicators are computed on the HydroEurasia (HE2) subbasins. These coincide with the elementary subbasins identified in the CCM2 hydrography, consisting of the subdivision of Europe and surrounding river basins into smaller polygons (average size about 7 km2). Each polygon represents a subbasin and is univocally associated to the main hydrographic segment (river stretch) it contains.

The indicators presented here reflect the best knowledge available at the JRC from both compiled European datasets and in-house model simulations. They are designed to be updated when more complete or higher-quality information is made available. Data and model limitations are highlighted for each indicator, either in this report or in Pistocchi et al., 2017.

[1] http://water.jrc.ec.europa.eu/waterportal/Water_Pressures_Indicators/

[2] Pistocchi, A., et al. *Assessment of the effectiveness of reported Water Framework Directive Programmes of Measures - Part II – development of a system of Europe-wide Pressure Indicators,* 2017. http://publications.jrc.ec.europa.eu/repository/handle/JRC105299

[3] http://land.copernicus.eu/local/riparian-zones

1. Introduction

This report illustrates a system of indicators (the JRC Water Pressure Indicators) providing a consistent picture of human pressures on water bodies at the European scale, to be compared with pressure and status information reported by Member States under the Water Framework Directive 60/2000/EC (WFD).

The datasets of the Pressure Indicators, introduced in Pistocchi et al. (2017), include quantitative indicators at the European scale representing major pressures acting on water bodies, including nutrients, urban runoff, hydromorphological and flow regime alterations.

This report describes version 2.0 of the JRC Pressure Indicators, whose version 1.0 was published before[4]. The indicators corresponding to the major pressure types to be reported by Member States under the 2016 WFD Reporting Guidance[5] are presented in Table 1, together with a brief description of the method of computation, and listed in Table 2.

Table 1, in particular, shows a clustering of the pressure categories reported by Member States. In comparison, Table 1 in Pistocchi et al., 2017 shows, for *all* pressure categories reported by member states, which indicator the JRC is producing or aims at producing in the future. Consequently, the list of indicators considered in Pistocchi et al., 2017, is logically broader than the list of indicators presented in this report. In particular, indicators of concentrations and loads of chemicals, biological oxygen demand (BOD), total suspended solids (TSS), as well as combined sewer overflows (CSO) are not covered in this report. Another aspect not covered in this report is groundwater (both quantity and quality), which will be addressed in a future phase.

All indicators are computed on the basis of the data model adopted by the JRC. This is based on the hydrography of CCM2 (deJaeger and Vogt, 2010)[6] where Europe is divided in 950472 elementary catchments of 7 km^2 average size. Each catchment has an elementary river stretch (the extent covered is 6,327,575 km2). The JRC data model is a hydrographically coherent geodatabase, named HydroEurasia (HE2), building on a previous geodatabase named HydroEurope (HE1) and is consistent with the European Environment Agency (EEA)'s Ecrins[7] which builds on an aggregation of the CCM2 subbasins. HE2 is a geospatial data model, where data are linked to the hydrological structure of the river network taking into account the hydrographic position and upstream/downstream relationships.

The indicators described in this report are available as maps at European scale with the resolution of CCM2 where not otherwise specified (see Table 2).

[4] http://water.jrc.ec.europa.eu/waterportal/Water_Pressures_Indicators/

[5] Annex 1A of the final draft of the WFD Reporting Guidance of 26th april 2016: http://cdr.eionet.europa.eu/help/WFD/WFD_521_2016/Guidance/WFD_ReportingGuidance.pdf

[6] http://ccm.jrc.ec.europa.eu/php/index.php?action=view&id=23

[7] http://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network

Pressure type (WFD Reporting Guidance 2016)[8]	Indicators and Methods
1.1 - Point – Urban waste water 1.3 - Point - IED plants 2.2 - Diffuse – Agricultural 2.6 - Diffuse - Discharges not connected to sewerage network 2.7 - Diffuse - Atmospheric deposition	Total N and total P concentrations Calculation of loads using the GREEN model and concentrations dividing GREEN loads by annual average discharge from the LISFLOOD model. Loads are apportioned to point and diffuse sources.
2.1 - Diffuse - Urban run-off	Dilution ratio of urban runoff in rivers Urban runoff estimation from daily precipitation of the LISFLOOD model setup
3.1 – Abstraction or flow diversion – Agriculture 3.2 – Abstraction or flow diversion – Public water supply 3.3 – Abstraction or flow diversion – Industry 3.4 – Abstraction or flow diversion – Cooling water	Flow duration curves (FDCs) from LISFLOOD hydrological model simulations describe natural water availability both in terms of annual volume, and duration. The ratio of water demand on annual volume in each river basin represents a potential Water Exploitation Index (WEI). The duration of flows below a natural flow threshold (the 10%ile and the 25%ile) are indicators of the worsening of low flow conditions.
3.5 – Abstraction or flow diversion – Hydropower	% of annual runoff in a river basin intercepted by dams
4.1.1 - Physical alteration of channel/bed/riparian area/shore - Flood protection	Artificial land cover in floodplains, from Corine Land Cover 2012 and Copernicus Riparian Zones Layer Density of infrastructure in floodplains, from Open Street Map infrastructure layers and Copernicus Riparian Zones Layer Riparian vegetation buffer width / floodplain width updated on Copernicus Riparian Zones Layer
4.1.2 - Physical alteration of channel/bed/riparian area/shore – Agriculture	Agricultural land cover in floodplains, from Corine Land Cover 2012 and Copernicus Riparian Zones Layer
4.2.1 - Dams, barriers and locks - Hydropower 4.2.2 - Dams, barriers and locks - Flood protection 4.2.3 - Dams, barriers and locks - Drinking water 4.2.4 - Dams, barriers and locks - Irrigation 4.2.5 - Dams, barriers and locks – Recreation 4.2.6 - Dams, barriers and locks – Industry 4.2.7 - Dams, barriers and locks – Navigation	Share of the length of stream network that is dams-free (i.e., theoretically accessible in the presence of stream barriers)

Table 1 –methods to derive the indicators presented in the report.

[8] Annex 1A of the final draft of the WFD Reporting Guidance of 26th april 2016: http://cdr.eionet.europa.eu/help/WFD/WFD_521_2016/Guidance/WFD_ReportingGuidance.pdf

Indicator short name	Description	Units
NConc	Nitrogen concentration (*)	mg N/l
PConc	Phosphorus concentration (*)	mg P/l
NShareAgri	Share of nitrogen load coming from agricultural sources	fraction
PShareAgri	Share of phosphorus load coming from agricultural sources	fraction
NSharePoint	Share of nitrogen load coming from point sources	fraction
PSharePoint	Share of phosphorus load coming from point sources	fraction
NShareOther	Share of nitrogen load coming from other sources [9]	fraction
PShareOther	Share of phosphorus load coming from other sources [9]	fraction
UrbRunoffShare	Dilution of urban runoff in rivers	fraction
DamIntcpRunoffShare	Share of catchment annual runoff captured by dams	fraction
DamFreeLengthShare	Share of stream network length accessible with barriers	fraction
Q10	Extra duration below natural 10% lowest flow	days
Q25	Extra duration below natural 25% lowest flow	days
Weic	Water Exploitation index based on consumption (WEI+)	fraction
ShareArtiFloodPlain	Share of artificial landuse in catchment floodplain	fraction
ShareAgriFloodPlain	Share of agricultural landuse in catchment floodplain	fraction
ShareNaturalFloodPlain	Share of natural landuse in catchment floodplain	fraction
InfrDensity	Density of infrastructure in floodplain	km/km2

Table 2 – indicators described in the report. (*) N and P concentrations are presented as classes.

2. Nutrients

Nutrient indicators are calculated using the GREEN model (Geospatial Regression Equation for European Nutrient losses; Grizzetti et al. 2012; Bouraoui et al. 2011) to predict annual loads of nitrogen (N) and phosphorus (P) from point and diffuse sources, at the spatial resolution of catchments.

For each catchment i, GREEN Computes the load of phosphorus or nitrogen according to the general relationship:

$L_i = (1\text{-}Lret_i)*(DS_i *(1\text{-}Bret_i)+ PS_i +U_i)*(1\text{-}Rret)_i$

with

[9] Other sources include scattered dwellings, atmospheric deposition and background losses

$(1\text{-}Bret_i) = f(\text{precipitation})$

$(1\text{-}Rret_i) = f(\text{river length})$

$(1\text{-}Lret_i) = f(\text{residence time, lake depth})$

and

L = Nutrient load (ton/yr)

DS = Nutrient diffuse sources (ton/yr)

PS = Nutrient point sources (ton/yr)

U = Nutrient load from upstream catchments (ton/yr)

Lret = Lake retention (fraction)

Bret = Basin retention (fraction)

Rret = River retention (fraction)

Further details are provided in Grizzetti et al., 2012.

Particularly, for nitrogen (N) the relationship is:

L = (1-Lret) * [(MinN + ManN + FixN + SoilN + (1-FF)*AtmN)*(1-Bret) + 0.38*FF*AtmN + 0.5*SdN + PsN + U] * (1-Rret)

With

MinN = Nitrogen mineral fertilisers (ton/yr)

ManN = Nitrogen in manure fertilisers (ton/yr)

FixN = Nitrogen fixation by leguminous crops and fodder (ton/yr)

SoilN = Nitrogen fixation by bacteria in soils (ton/yr)

AtmN = Nitrogen deposition from atmosphere (ton/yr)

SdN = Nitrogen input from scattered dwellings (ton/yr)

PsN = Nitrogen input from point sources (ton/yr)

U = Nitrogen load from upstream catchments (ton/yr)

FF = Forest land cover in the catchment (fraction)

Background losses for nitrogen are estimated as 0.38*FF*AtmN. For an atmospheric deposition of 10 kgN/ha this corresponds to a background of 3.8 kgN/ha.

Similarly, for phosphorus (P):

L = (1-Lret) * [(MinP + ManP + (1-FF)*BgP)*(1-Bret) + FF*BgP + 0.5*SdP + PsP + U] * (1-Rret)

With

MinP = Phosphorus mineral fertilisers (ton/yr)

ManP = Phosphorus in manure fertilisers (ton/yr)

BgP = Phosphorus background losses (ton/yr)

SdP = Phosphorus input from scattered dwellings (ton/yr)

PsP = Phosphorus input from point sources (ton/yr)

U = Phosphorus load from upstream catchments (ton/yr)

FF = Forest land cover in the catchment (fraction)

Background losses for phosphorus are estimated at 0.15 kgP/ha.

Compared to previous applications of GREEN (v.1.0), described in Pistocchi et al., 2017, the current setup of GREEN (v.2.0) presents some changes, summarized in the following table.

Feature	**GREEN v1.0**	**GREEN v2.0**
Geodatabase	HydroEurope (HE1) Average catchment size 180 km^2	HydroEurasia (HE2) Average catchment size 7 km^2 Higher spatial resolution of rivers (CCM) and lakes (Ecrins) delineation
Calibration	1985-2005 Measurements of nutrient load from national agencies	2005-2012 Measurements of nutrient load reported by Member States (EEA WaterBase v14)
Diffuse source input	Land use and fertiliser maps developed ad hoc based on CAPRI model	Land use of GREEN 2005, fertiliser maps of GREEN 2005 updated by annual variation from EUROSTAT
Point source input	Point sources estimated (by population density, level of connection and treatment per country)	Point sources reported by EU Member States under the Urban WWT Directive[10] and E-PRTR[11]

Table 3 – changes compared to previous GREEN setup.

The model has been calibrated against loads estimated from monitored concentrations, with reference to the year 2012. Total nitrogen and phosphorus concentration monitored by Member States were taken as reported to the EEA (WaterBase v14). As water flow data were absent or without temporal information attached, the flow simulated by the model LISFLOOD, multiplied by the monitored concentration, was used to compute the loads. The points available and adopted for calibration are shown in Figure 1. The calibration results are presented in the scatter plots of Figure 2. Figure 3 shows N and P concentration distributions computed by GREEN (indicators Nconc and Pconc in Table 2) for illustration purposes, while Figure 4 and Figure 5 show the statistical distribution of values by European Member State for the Nconc and Pconc indicators.

[10] https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-4

[11] http://prtr.ec.europa.eu/#/home

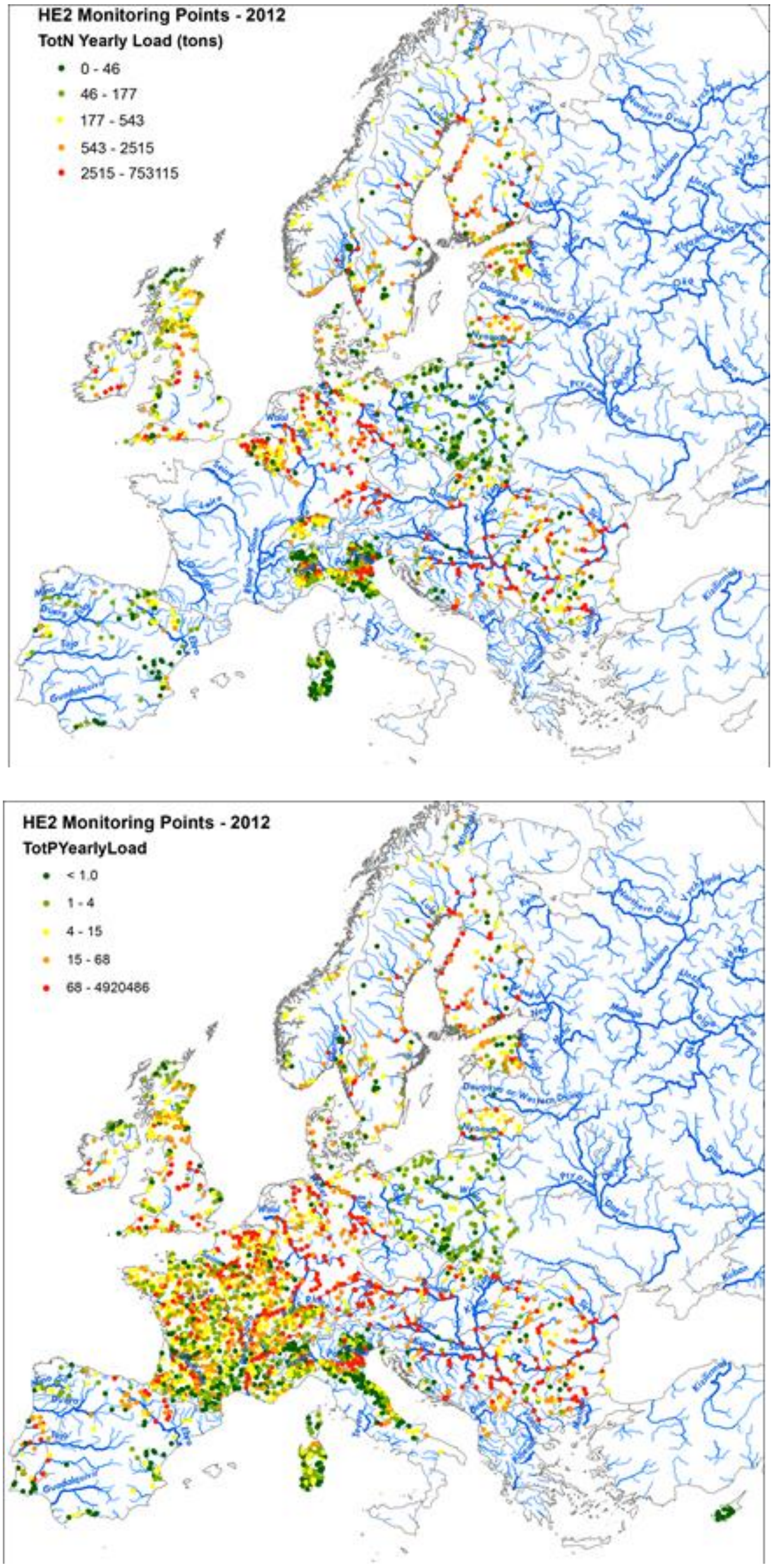


Figure 1 – monitoring points used for GREEN calibration on P and N (tonnes)

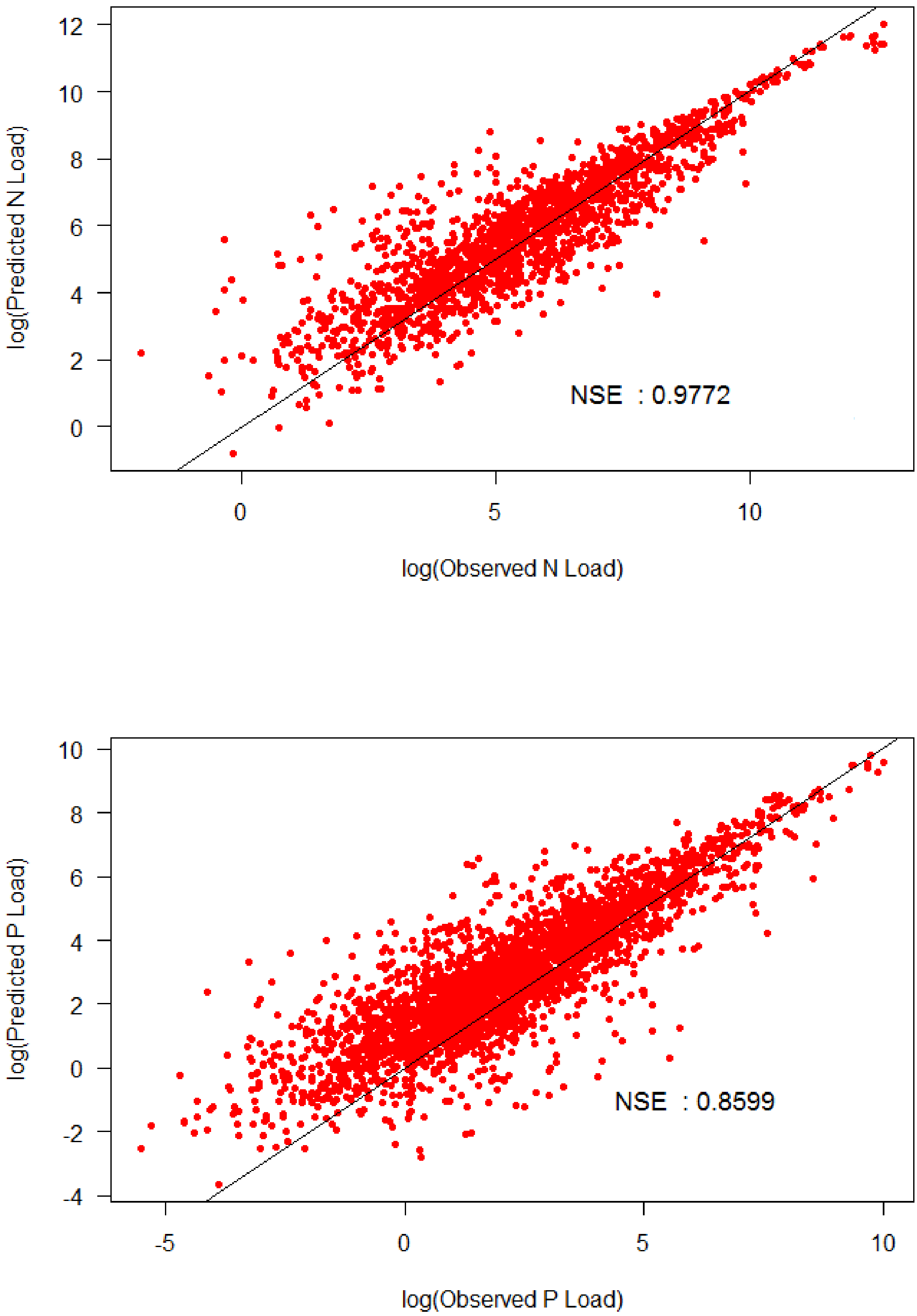


Figure 2 – scatter plots of observed and computed loads for N and P. NSE = Nash-Sutcliffe Efficiency

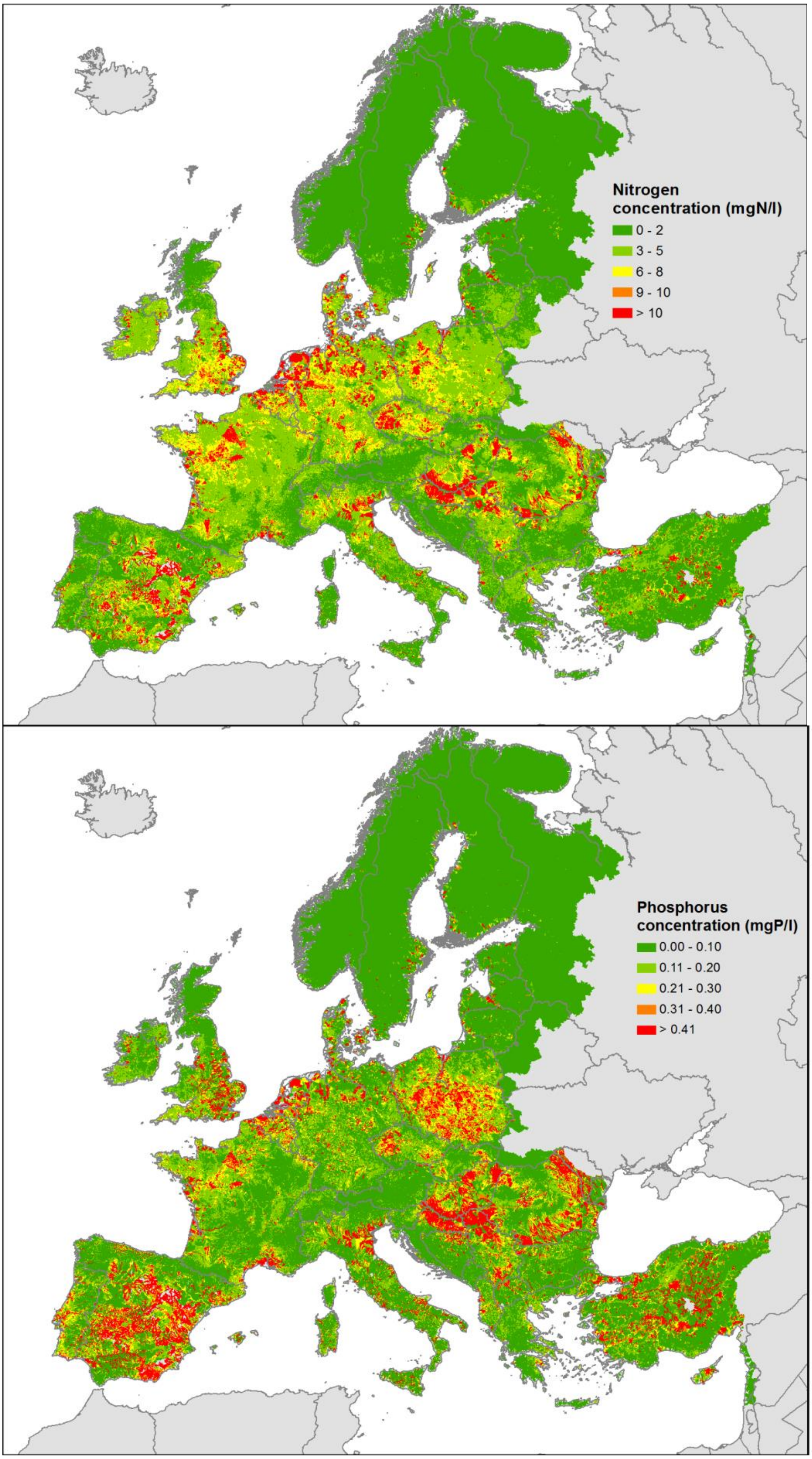


Figure 3 – Indicators Nconc and Pconc (nitrogen and phosphorus concentration).

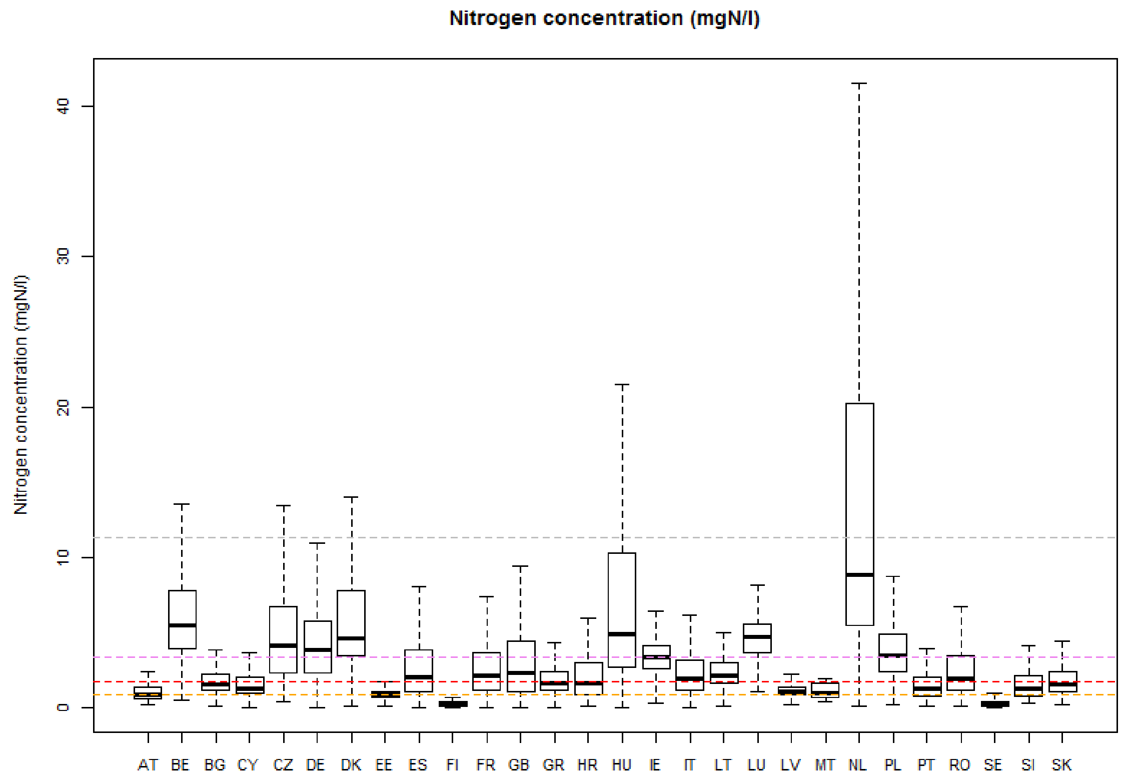
(A)

Country	n	trimmed_mean	median	Q.25.	Q.75.	IQR	Winsor_std
AT	36774	0.90	0.81	0.52	1.28	0.76	0.54
BE	2399	5.85	5.49	3.96	7.79	3.83	2.65
BG	16419	1.67	1.56	1.09	2.20	1.11	0.86
CY	554	1.44	1.27	0.89	1.97	1.08	0.85
CZ	10163	4.55	4.11	2.28	6.73	4.45	3.07
DE	36290	4.00	3.81	2.24	5.71	3.47	2.37
DK	1303	6.13	4.58	3.42	7.71	4.29	7.68
EE	2736	0.87	0.83	0.65	1.06	0.41	0.36
ES	81438	2.44	1.95	1.00	3.81	2.81	2.33
FI	28578	0.22	0.20	0.12	0.32	0.20	0.14
FR	86873	2.32	2.04	1.09	3.61	2.52	1.56
GB	22774	2.69	2.30	1.07	4.38	3.31	2.02
GR	35737	1.73	1.61	1.10	2.39	1.29	0.85
HR	9104	2.27	1.65	0.88	2.91	2.03	3.36
HU	5558	6.57	4.86	2.69	10.23	7.54	6.36
IE	6676	3.37	3.38	2.57	4.12	1.55	1.05
IT	88151	2.16	1.92	1.14	3.15	2.01	1.45
LT	5871	2.27	2.12	1.61	2.95	1.35	0.89
LU	317	4.63	4.71	3.64	5.55	1.92	1.29
LV	4832	1.11	1.03	0.82	1.36	0.54	0.46
MT	5	1.10	0.89	0.68	1.58	0.91	0.57
NL	577	15.10	8.84	5.48	20.22	14.74	23.66
PL	25300	3.64	3.48	2.33	4.90	2.57	1.72
PT	13621	1.39	1.23	0.76	2.02	1.26	0.92
RO	30271	2.35	1.87	1.17	3.40	2.22	1.98
SE	36637	0.25	0.15	0.08	0.40	0.33	0.32
SI	6648	1.43	1.25	0.72	2.09	1.36	1.03
SK	10058	1.71	1.50	1.00	2.37	1.37	1.07

(B)

Country	n	trimmed_mean	median	Q.25.	Q.75.	IQR	Winsor_std
AT	36774	0.03	0.03	0.02	0.05	0.03	0.02
BE	2399	0.23	0.22	0.13	0.33	0.20	0.15
BG	16419	0.07	0.07	0.05	0.10	0.05	0.04
CY	554	0.20	0.13	0.08	0.30	0.22	0.27
CZ	10163	0.12	0.10	0.06	0.18	0.12	0.10
DE	36290	0.10	0.09	0.05	0.14	0.09	0.06
DK	1303	0.14	0.10	0.07	0.17	0.11	0.17
EE	2736	0.03	0.03	0.02	0.04	0.01	0.01
ES	81438	0.16	0.09	0.05	0.26	0.21	0.23
FI	28578	0.03	0.03	0.02	0.04	0.01	0.01
FR	86873	0.08	0.07	0.05	0.12	0.07	0.05
GB	22774	0.07	0.06	0.03	0.11	0.08	0.07
GR	35737	0.08	0.07	0.05	0.10	0.05	0.04
HR	9104	0.09	0.05	0.03	0.10	0.07	0.17
HU	5558	0.35	0.26	0.13	0.57	0.45	0.36
IE	6676	0.10	0.09	0.07	0.12	0.05	0.03
IT	88151	0.07	0.06	0.04	0.10	0.07	0.05
LT	5871	0.05	0.05	0.03	0.07	0.04	0.03
LU	317	0.14	0.12	0.07	0.20	0.13	0.07
LV	4832	0.04	0.03	0.03	0.05	0.02	0.02
MT	5	0.01	0.01	0.01	0.02	0.00	0.00
NL	577	0.36	0.23	0.12	0.54	0.42	0.60
PL	25300	0.18	0.15	0.09	0.28	0.19	0.13
PT	13621	0.12	0.10	0.06	0.18	0.12	0.09
RO	30271	0.12	0.09	0.05	0.18	0.13	0.12
SE	36637	0.03	0.03	0.02	0.04	0.01	0.01
SI	6648	0.07	0.06	0.03	0.11	0.08	0.06
SK	10058	0.07	0.06	0.04	0.11	0.07	0.06

Figure 4 – statistics of the indicators (A) Nconc, (B) Pconc, by country: number of elementary catchments assessed(n), trimmed mean, median, 25%ile (Q.25), 75%ile (Q.75), inter-quartile range (IQR), winsorized standard deviation (Winsor _std).



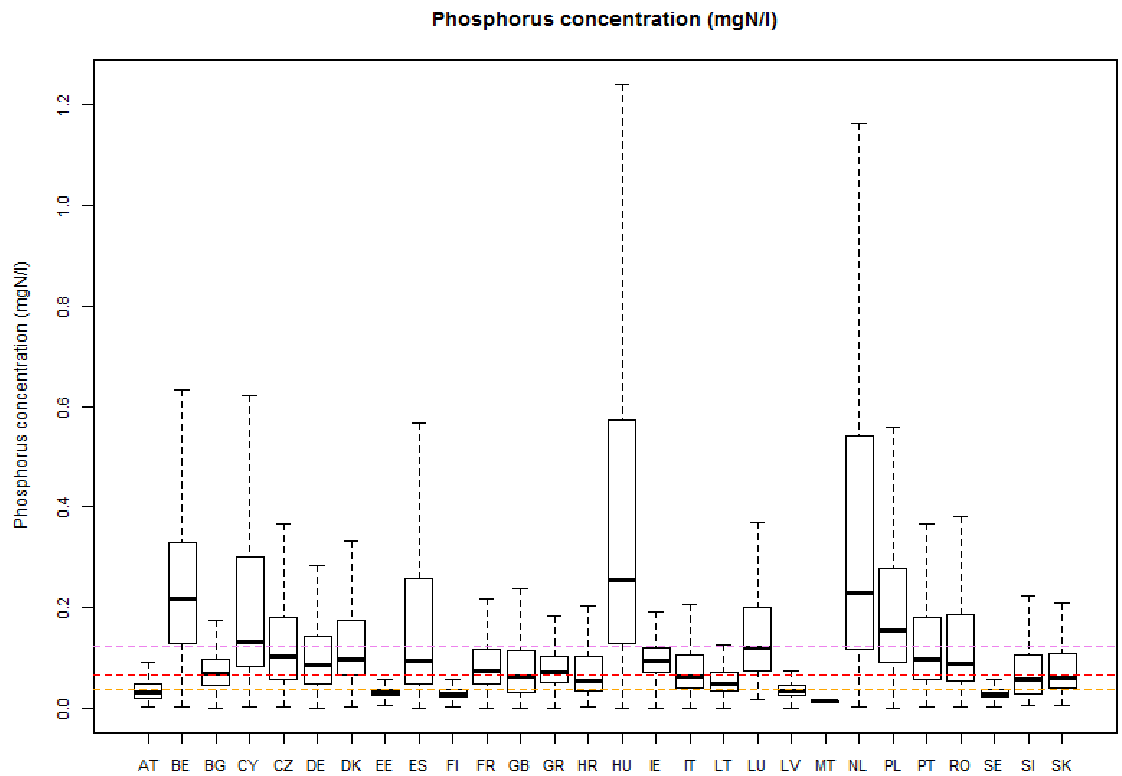


Figure 5 – box plots of Nconc and Pconc by country. Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values; the grey line corresponds to 50 mg NO3/l (limits for the Nitrates Vulnerable Zones).

3. Urban runoff

As an indicator of pollution by urban runoff, we compute the dilution ratio of runoff generated on urban surfaces (UrbRunoffShare in Table 2). We assume that runoff from urban areas is quick and does not depend on the state of the land surface, as it is mainly controlled by impervious surfaces and artificial drainage. Hence, it can be represented as a fraction (the "runoff coefficient") of the annual precipitation on a given urban area. We distinguish urban areas based on the Corine Land Cover classification (Table 4). Precipitation is taken from the LISFLOOD model setup.

CLC class	Runoff coefficient φ
Continuous urban fabric	0.9
Discontinuous urban fabric	0.5
Industrial or commercial units	0.9
Road and rail networks and associated land	0.9
Port areas	0.9
Airports	0.9
Mineral extraction sites	0.5
Construction sites	0.5

Table 4 – assumptions on runoff coefficients for the urban runoff indicator

For a given elementary catchment in CCM2, we compute urban runoff generated in the catchment upstream by summing annual precipitation flow (precipitation depth times surface area) on the different urban areas, each multiplied by its runoff coefficient, and we divide it by the annual average discharge through the elementary catchment, Q, as:

$$\text{UrbRunoffShare} = \frac{\sum_i \varphi_i P_i}{Q}$$

Where the summation refers to urban areas in the catchment upstream, P_i is precipitation flow in each urban area and φ_i is the respective runoff coefficient.

The following Figure 6 and Figure 7 show the maps of the indicators as well as their distribution by country in the EU.

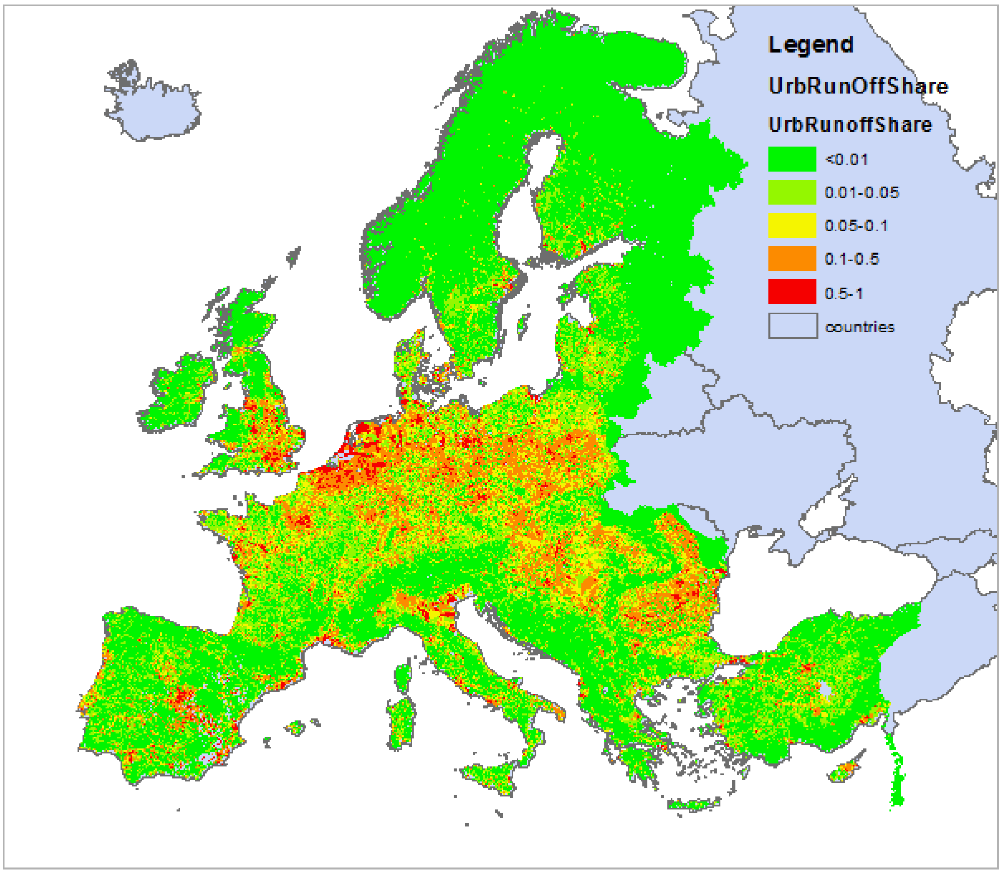


Figure 6 – map of the indicator "UrbRunoffShare"

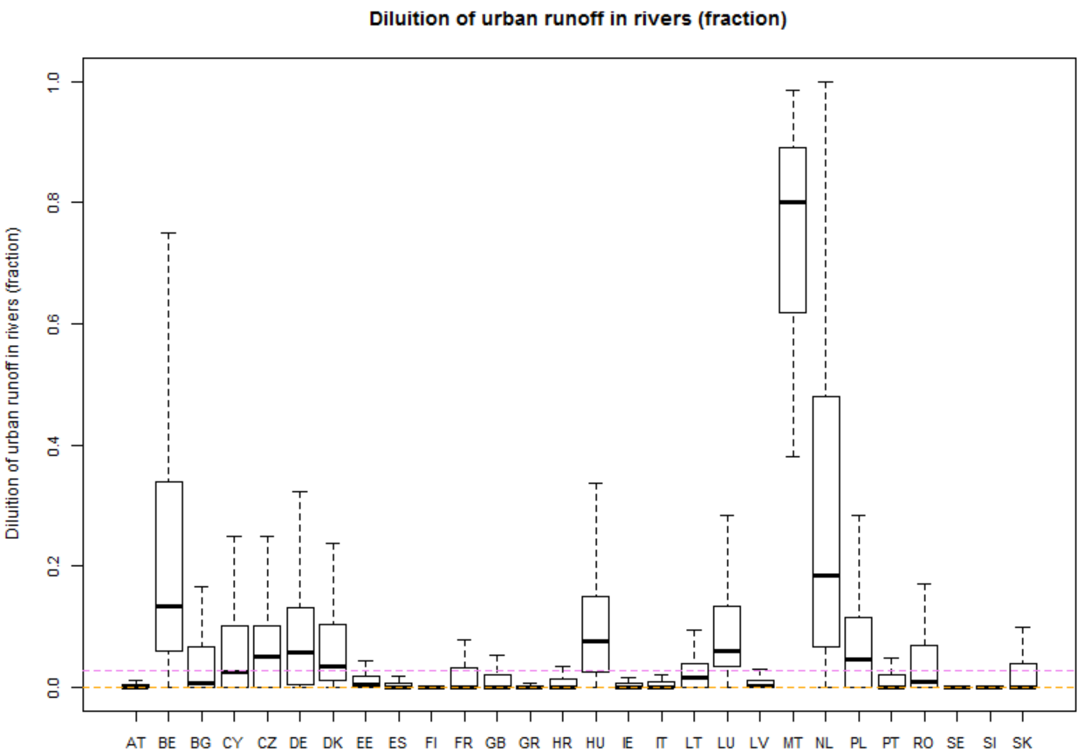


Figure 7 – boxplot of country values of the indicator "UrbRunoffShare". Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values.

4. Flow regime

We consider two types of indicators of flow regime alteration, which are computed for each cross section of the stream network.

The first one is the ratio of consumptive water use volume, on the volume of flow yearly available under natural conditions. This indicator is the "water exploitation index" (WEI+) based on consumption (Indicator Weic in Table 2). This indicator is computed with the current LISFLOOD model setup, accounting for water use as discussed e.g. in de Roo et al., 2012.

The second one is the reduction of low flow durations, or the number of additional days in the year, when a given threshold discharge is not exceeded or equalled in the river due to abstractions, in comparison with natural conditions. In particular, we refer to the discharge exceeded or equalled 90% of the year (Indicator Q_{10} in Table 2) and that exceeded or equalled 25% of the year (indicator Q_{25} in Table 2).

The second indicator requires estimating the "flow duration curve" (FDC) at each cross section. FDCs represent the cumulative frequency of exceedance of discharges in a river, are a synthetic representation of the catchment behavior. They are often plotted in the form of discharges as a function of the number of days in the year, in which those discharges are equalled or exceeded. Vogel and Fennessey, 1995, review and discuss applications of FDCs for several aspects of river basin management.

Indicators Q_{10} and Q_{25} are computed by comparing the natural FDC and the FDC under abstractions. Figure 8 illustrates graphically the concept of these two indicators. At the time of writing this report, the LISFLOOD model was under calibration to incorporate an updated representation of abstractions having significant implications on the representation of FDCs. In this report we present a preliminary, approximated evaluation where the calibrated LISFLOOD model is used to simulate FDCs under natural flow conditions, by excluding abstractions and the operation of dams.

A conventional FDC corresponding to abstraction conditions is then computed assuming that (1) no abstraction occurs at very low flows (when discharges have a duration of 95% of the year or more, Q_5), and (2) abstraction intensity is proportional to available flow above Q_5, with a proportionality constant given by[12]:

$$1 - \alpha = \frac{D}{31536000 \int_0^{0.95} q(\tau) d\tau - 0.95 * 31536000\, Q_5};$$

with D= total annual demand (sum of irrigation, public, industrial, energy production and livestock), $q(\tau)$ discharge with duration τ.

The FDC under conditions of abstractions is computed as:

$$q * (\tau) = Q_5 + \alpha(q(\tau) - Q_5).$$

Abstractions are assumed to coincide with water demand in the catchment upstream of each cross section. The latter is estimated separately for the different use categories presently addressed at the JRC, namely:

- Public water use
- Industrial water use
- Demand for energy production plant cooling
- Demand for livestock breeding.
- Irrigation demand

[12] The formula holds with demand in m3/year and discharges in m^3/s, 31536000 being the number of seconds in a year.

Public, industrial and energy demands are derived with the procedures described in Vandecasteele et al., 2013, and Vandecasteele et al., 2014. Livestock breeding water demand is estimated by Mubareka et al., 2013. The year of reference for water demand is 2006, and we assume that no significant change in spatial patterns and intensity of demand has occurred until present time. For irrigation, we use a spatially distributed implementation of the EPIC model (Bouraoui and Aloe, 2007) to estimate annual crop water requirements based on a long-term simulation period (1990-2010). The model setup used to estimate the average irrigation requirements is based on crop distribution statistics defined at 5km resolution derived from the combination of CAPRI (Britz, 2004), SAGE (Monfreda et al., 2008) and GLC (Bartholomé and Belward, 2005). The amount of manure and mineral fertilization applied were retrieved from the Common Agricultural Policy Regionalized Impact (CAPRI) agro-economic model (Britz and Witzke, 2008) and crop production optimized according to EUROSTAT statistics at NUTS2 level (EUROSTAT, 2010a). Extension of irrigated land by crop was derived according to MIRCA dataset (Portmann, 2011) and applied irrigated volume were validated at country level by using EUROSTAT 2010 statistics (EUROSTAT, 2010b). Landuse and crop management is assumed constant for the whole period of simulation.

The assumption that water demand from the different sectors represents abstractions from the stream network is obviously a crude approximation of abstraction in reality, for the following reasons:

- A part of demand can be unmet;
- Abstractions do not occur only from surface water, but also from groundwater
- Abstractions can exceed demand due to transmission losses from the abstraction point to use sites; evaporation of water stored in open reservoirs may be also important.

However, the uncertainty on the modalities, timing and spatial distribution of actual abstractions can be considerably higher than the uncertainty on water demand.

The indicator will be updated with the new LISFLOOD model incorporating an updated representation of abstractions, as soon as available.

The following figures show the maps of the indicators as well as the distribution of indicator "Weic" (WEI+) by country in the EU.

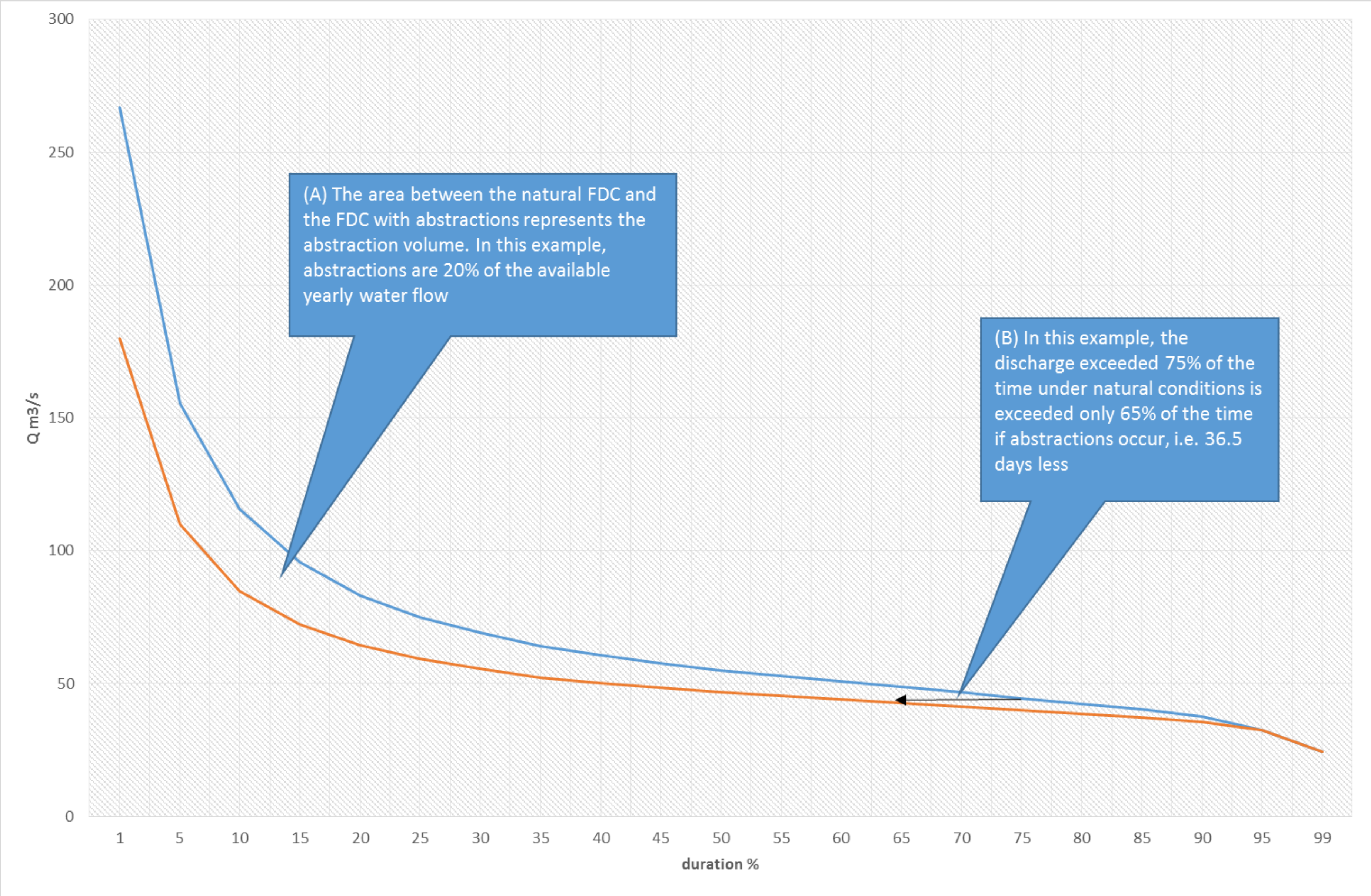


Figure 8 – example of comparison of flow duration curves under natural conditions (blue line) and with abstractions (orange line).

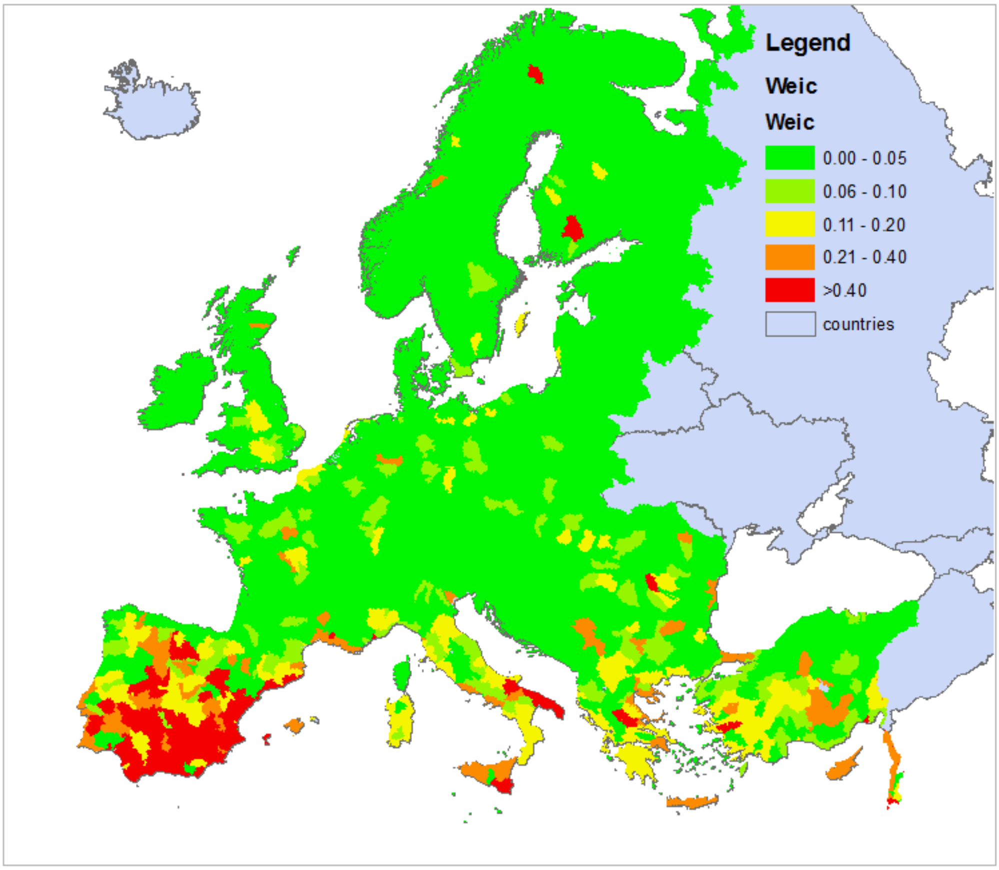


Figure 9 – map of the indicator "Weic" (WEI+)

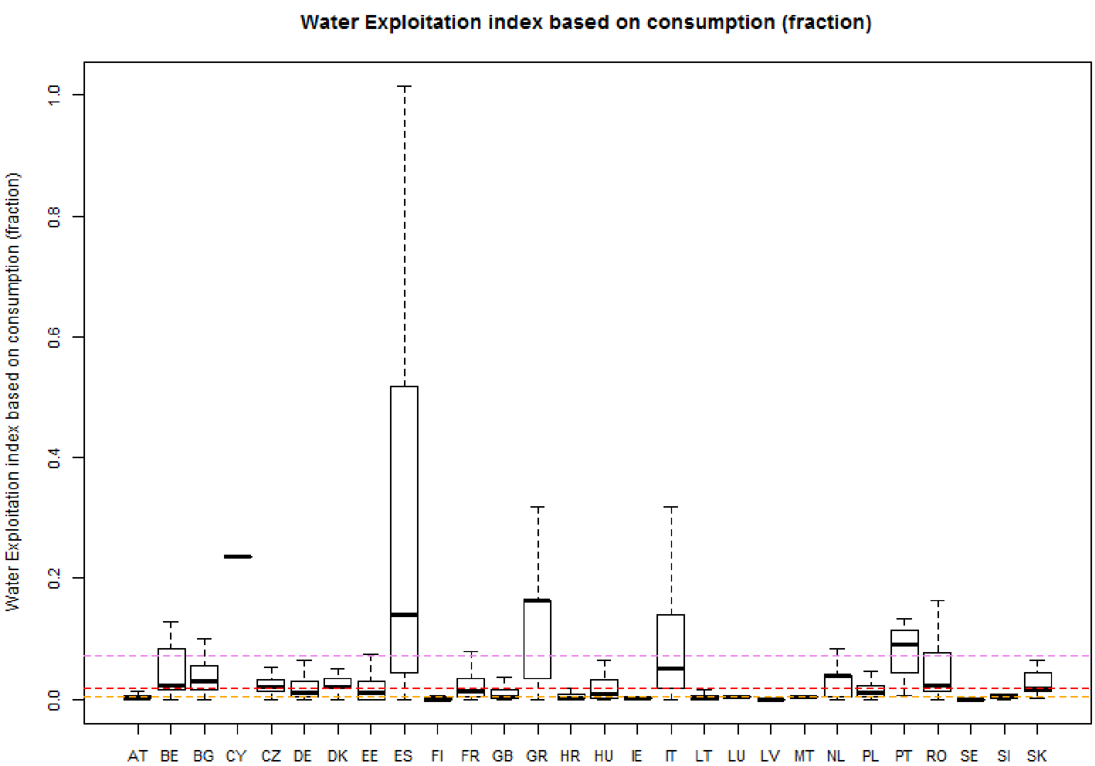


Figure 10 – boxplot of country values of the indicator "Weic" (WEI+). Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values

Country	n	trimmed_mean	median	Q.25.	Q.75.	IQR	Winsor_std
AT	36774	0.00	0.00	0.00	0.01	0.00	0.00
BE	2413	0.04	0.02	0.02	0.08	0.07	0.03
BG	16537	0.04	0.03	0.02	0.06	0.04	0.06
CY	897	0.24	0.24	0.24	0.24	0.00	0.00
CZ	10163	0.02	0.02	0.01	0.03	0.02	0.01
DE	36953	0.02	0.01	0.00	0.03	0.03	0.02
DK	2454	0.02	0.02	0.02	0.04	0.02	0.01
EE	3510	0.02	0.01	0.00	0.03	0.03	0.01
ES	85590	0.25	0.14	0.04	0.52	0.47	0.30
FI	45354	0.00	0.00	0.00	0.00	0.00	0.00
FR	89365	0.02	0.01	0.00	0.03	0.03	0.02
GB	27859	0.01	0.00	0.00	0.02	0.01	0.02
GR	44401	0.13	0.16	0.04	0.16	0.13	0.08
HR	12231	0.00	0.00	0.00	0.01	0.01	0.00
HU	5588	0.02	0.01	0.00	0.03	0.03	0.05
IE	8458	0.00	0.00	0.00	0.00	0.00	0.00
IT	93235	0.07	0.05	0.02	0.14	0.12	0.07
LT	5890	0.00	0.00	0.00	0.01	0.01	0.00
LU	317	0.00	0.00	0.00	0.00	0.00	0.00
LV	5064	0.00	0.00	0.00	0.00	0.00	0.00
MT	25	0.00	0.00	0.00	0.00	0.00	0.00
NL	1079	0.03	0.04	0.00	0.04	0.04	0.03
PL	25519	0.01	0.01	0.01	0.02	0.02	0.01
PT	14064	0.11	0.09	0.04	0.12	0.07	0.13
RO	30399	0.04	0.02	0.01	0.08	0.07	0.05
SE	45964	0.00	0.00	0.00	0.00	0.00	0.00
SI	6662	0.00	0.01	0.00	0.01	0.01	0.00
SK	10058	0.03	0.02	0.01	0.04	0.03	0.02

Figure 11- – statistics of the indicator Weic (WEI+), by country: number of elementary catchments assessed(n), trimmed mean, median, 25%ile (Q.25), 75%ile (Q.75), inter-quartile range (IQR), winsorized standard deviation (Winsor _std).

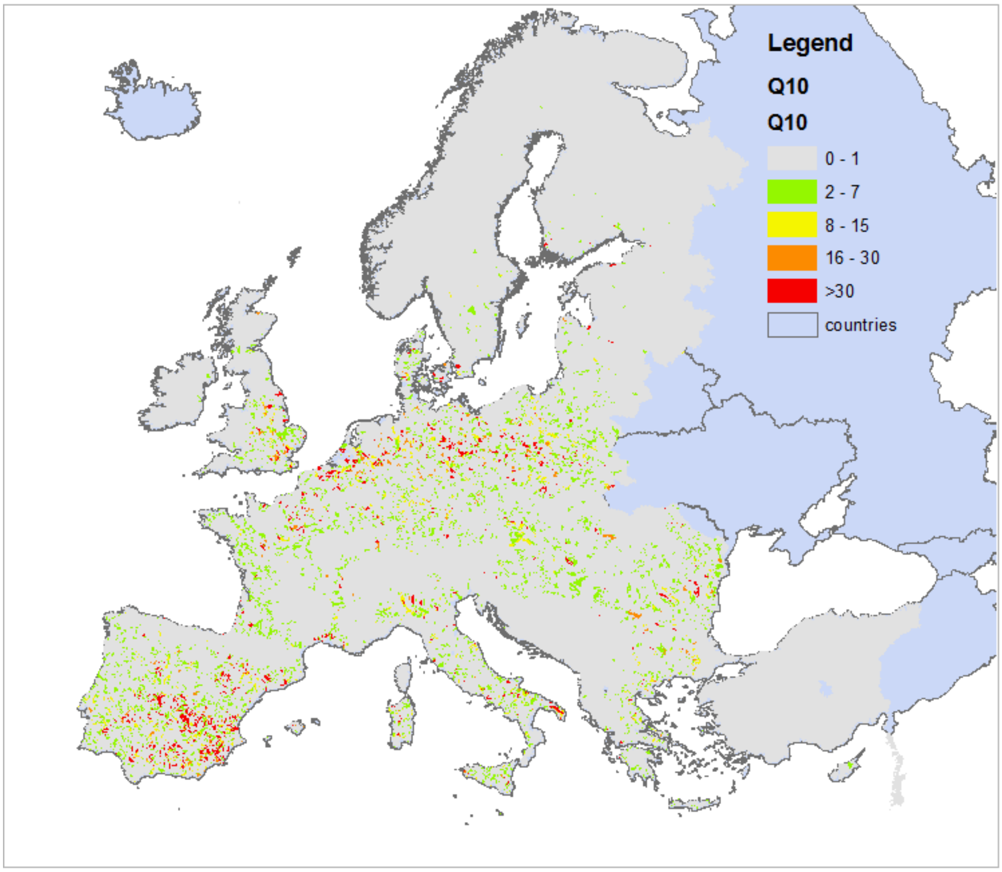


Figure 12 – map of the indicator "Q_{10}"

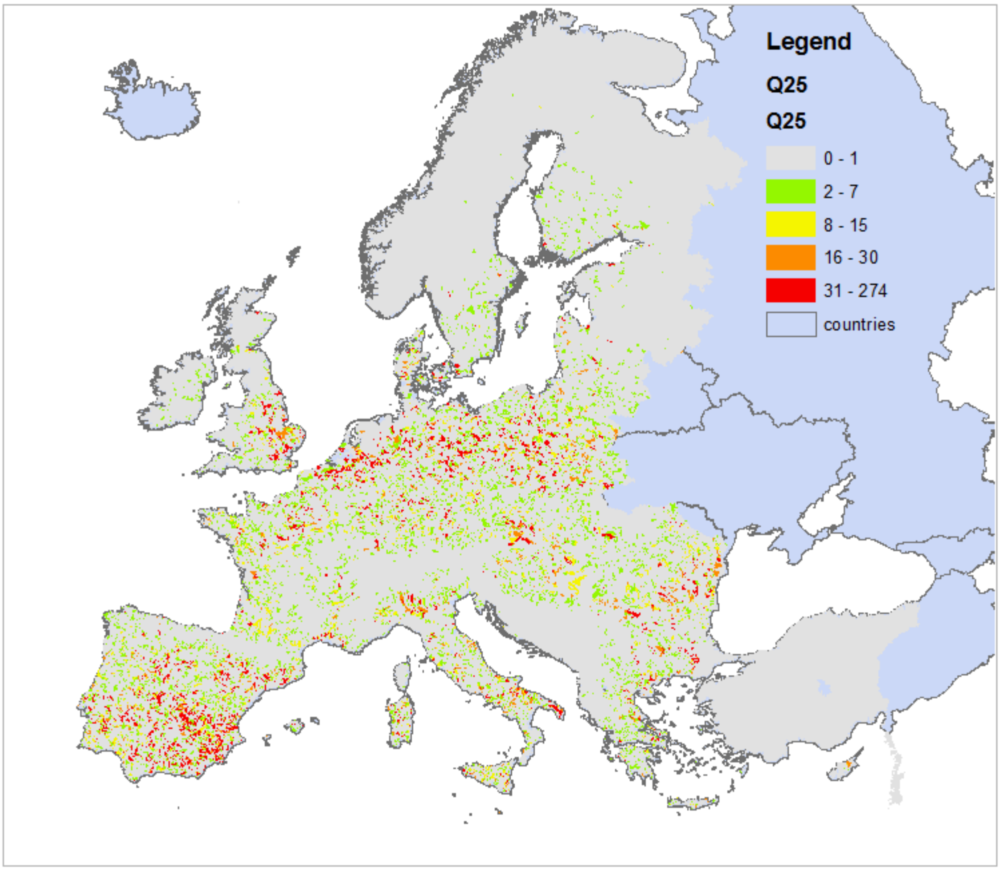


Figure 13 – map of the indicator "Q_{25}"

5. Hydromorphological alteration

We consider two aspects of hydromorphological alteration, namely:

- The encroachment of floodplains with agricultural land uses, urban areas and infrastructure and the removal of natural vegetation
- The interruption of river continuity due to stream barriers
- The alteration of flow regime due to the presence of dams with reservoirs.

Floodplains indicators include the share of artificial and agricultural land cover (Corine Land Cover (CLC) v. 2012, level 1 categories 1 and 2 respectively) and the density of infrastructure (based on the infrastructure mapped in OpenStreetMap[13]) as well as the ratio of the riparian vegetation buffer width along rivers, divided by the width of the floodplain. The latter is take from Weissteiner et al., 2016. These correspond to indicators "ShareArtiFloodPlain", "ShareAgriFloodPlain", "InfrDensity" and "ShareNaturalFloodPlain", respectively, in Table 2.

It should be noted that the representation of artificial land cover allowed by the CLC may lead to underestimation, because infrastructure - such as roads and railways- is often not visible at the resolution of this dataset.

The indicator of river continuity interruption due to stream barriers (DamFreeLengthShare in Table 2) is computed as follows, with reference to the CCM2 hydrography. For each stream segment, we compute the total length of stream network to which it belongs (SL_N). This coincides with the sum of the lengths of the stream segments in the river basin, closed at the sea outlet, to which each segment belongs. We then compute for each segment, the sum of the lengths of segments accessible in the presence of dams (SL_D). Stream segments are accessible from a given segment if there is no dam in between. The indicator is the ratio:

$$\text{DamFreeLengthShare} = \frac{SL_D}{SL_N}$$

This represents conceptually the share of naturally available habitat, which is still available in the presence of dams.

The alteration of flow regime due to dams is represented through the following indicator. We first compute the annual average discharge at each dam. For each elementary catchment, we calculate the sum of all annual average discharges at dams in the catchments upstream, and we divide this sum by the annual average discharge of the elementary catchment. This indicator ("DamIntcpRunoffShare" in Table 2) represents conceptually the share of the annual discharge which is intercepted by dams in a river basin, potentially associated to the magnitude of hydropeaking flow and seasonal flow shifts.

The following figures show the maps of the indicators as well as their distribution by country in the EU.

[13] https://www.openstreetmap.org

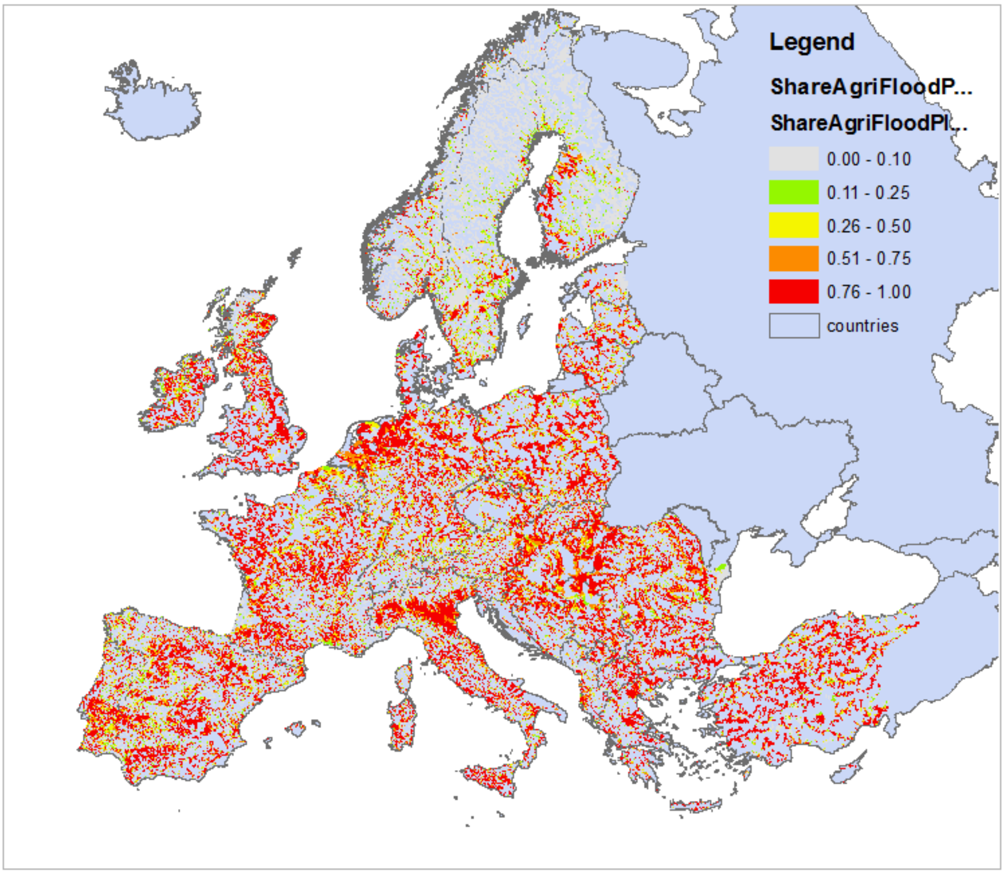


Figure 14 – map of the indicator "ShareAgrifloodplain"

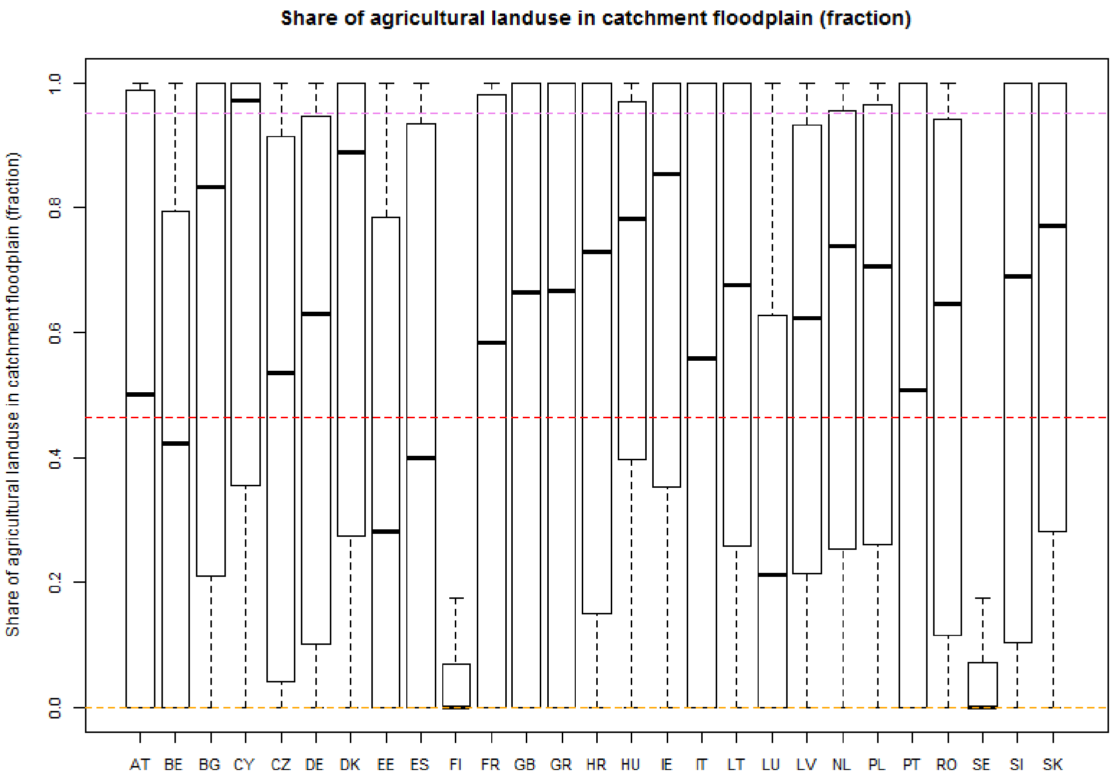


Figure 15 – boxplot of country values of the indicator "ShareAgrifloodplain". Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values.

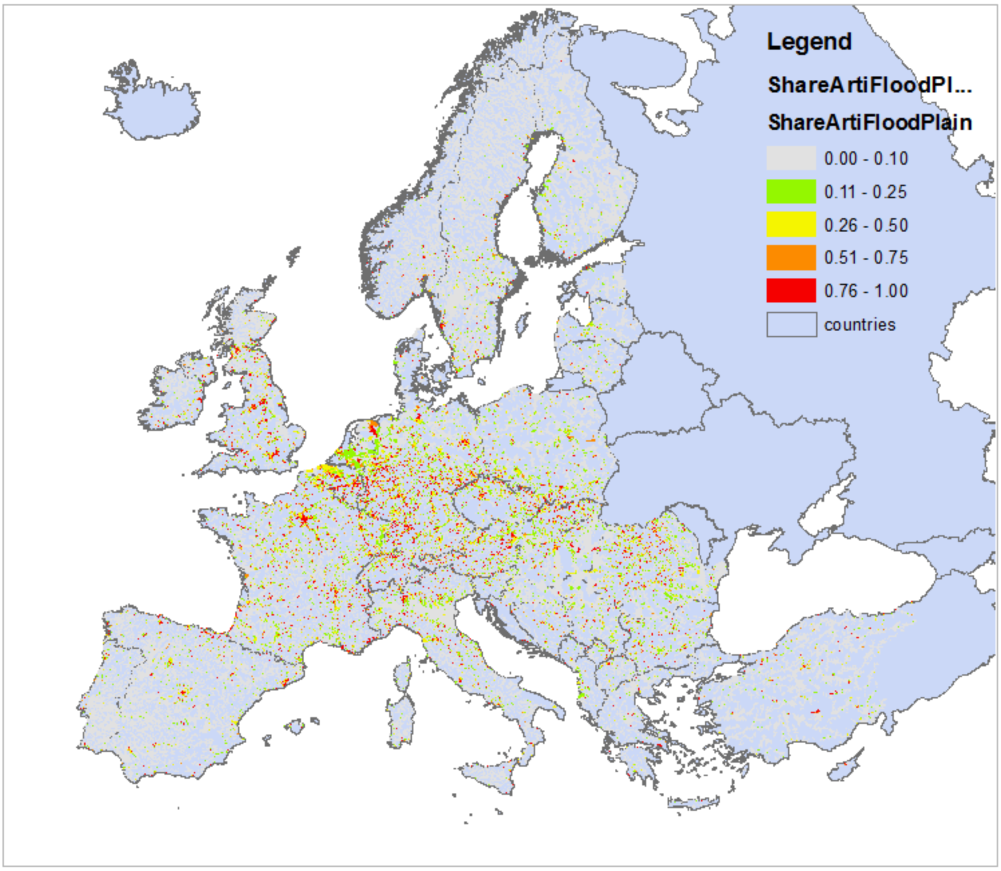


Figure 16 – map of the indicator "ShareArtifloodplain"

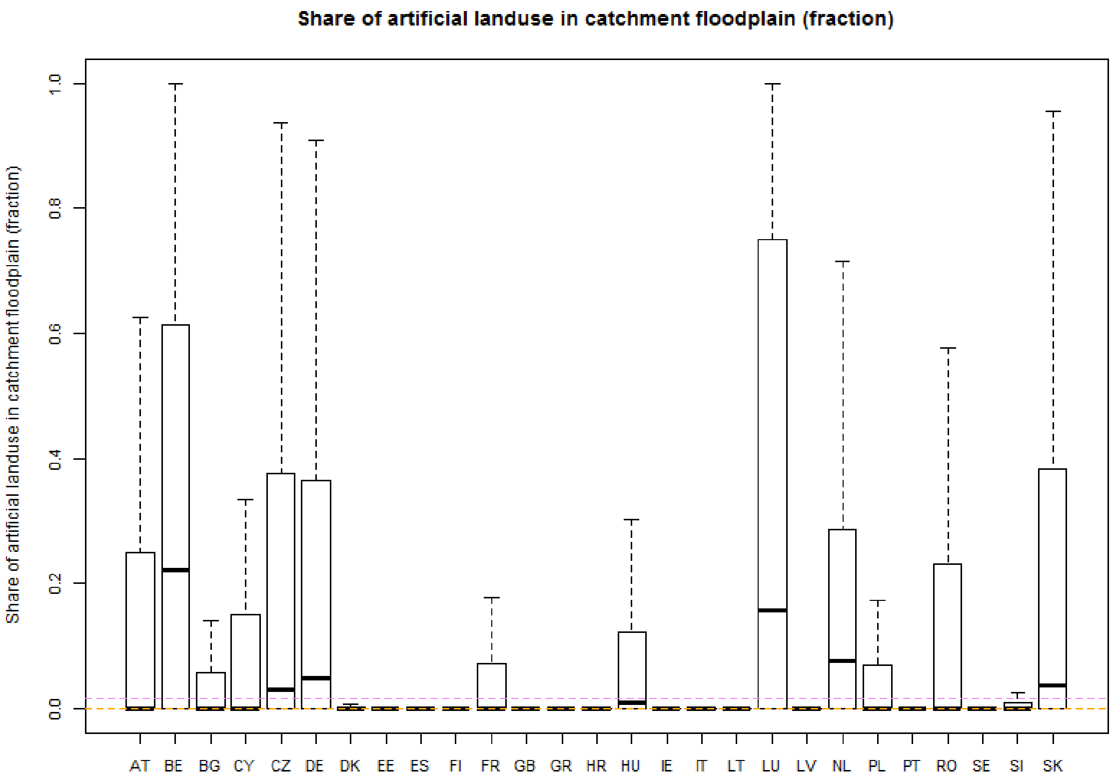


Figure 17 – boxplot of country values of the indicator "ShareArtifloodplain" . Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values.

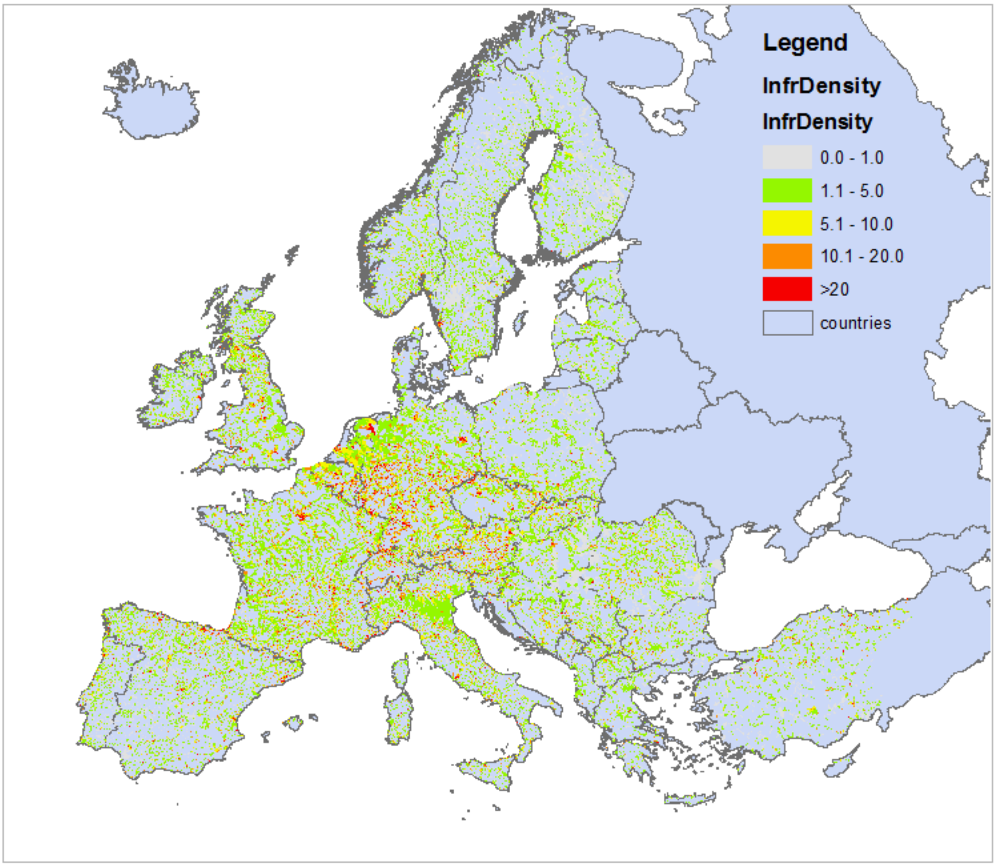


Figure 18 – map of the indicator "InfrDensity"

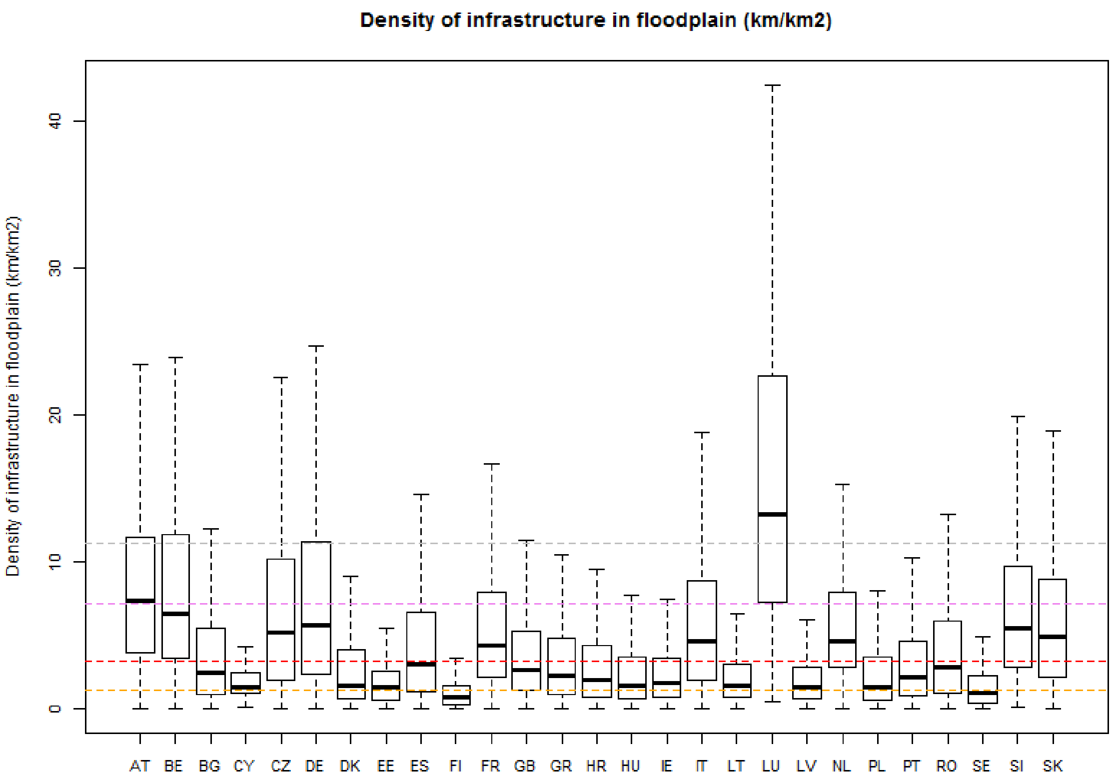


Figure 19 – boxplot of country values of the indicator "InfrDensity" . Horizontal lines: yellow=25th percentile, red=median, pink=75th percentile of European values.

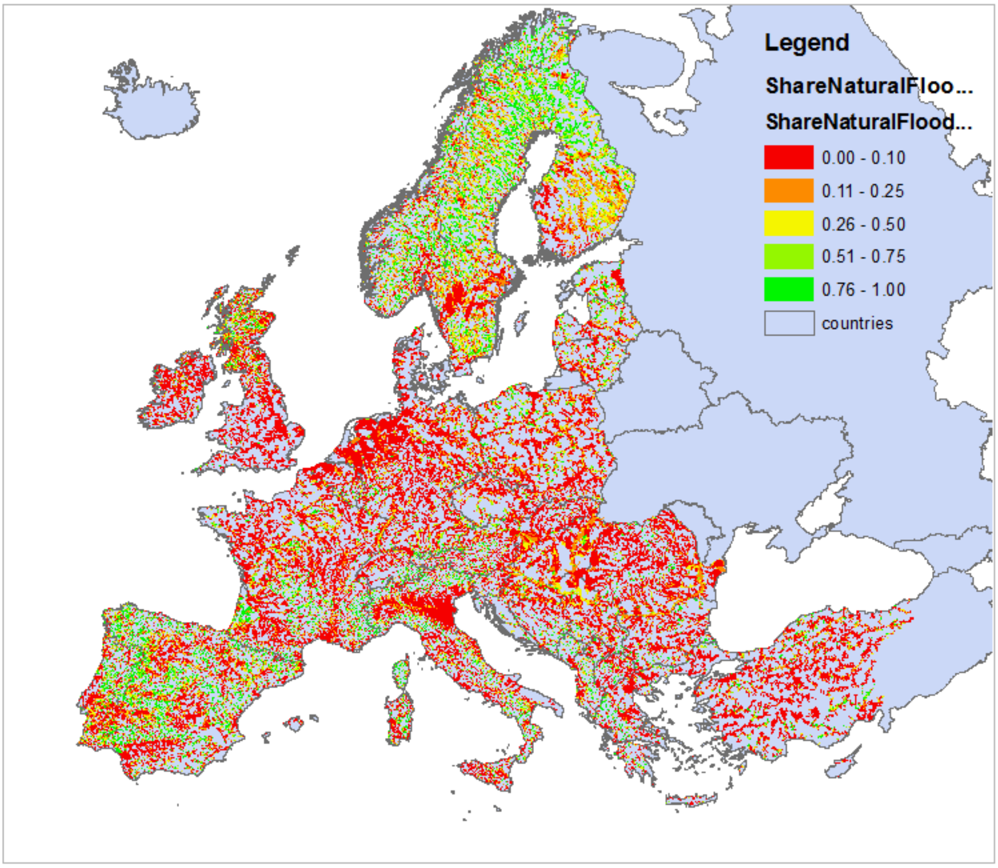


Figure 20 – map of the indicator "ShareNaturalFloodplain"

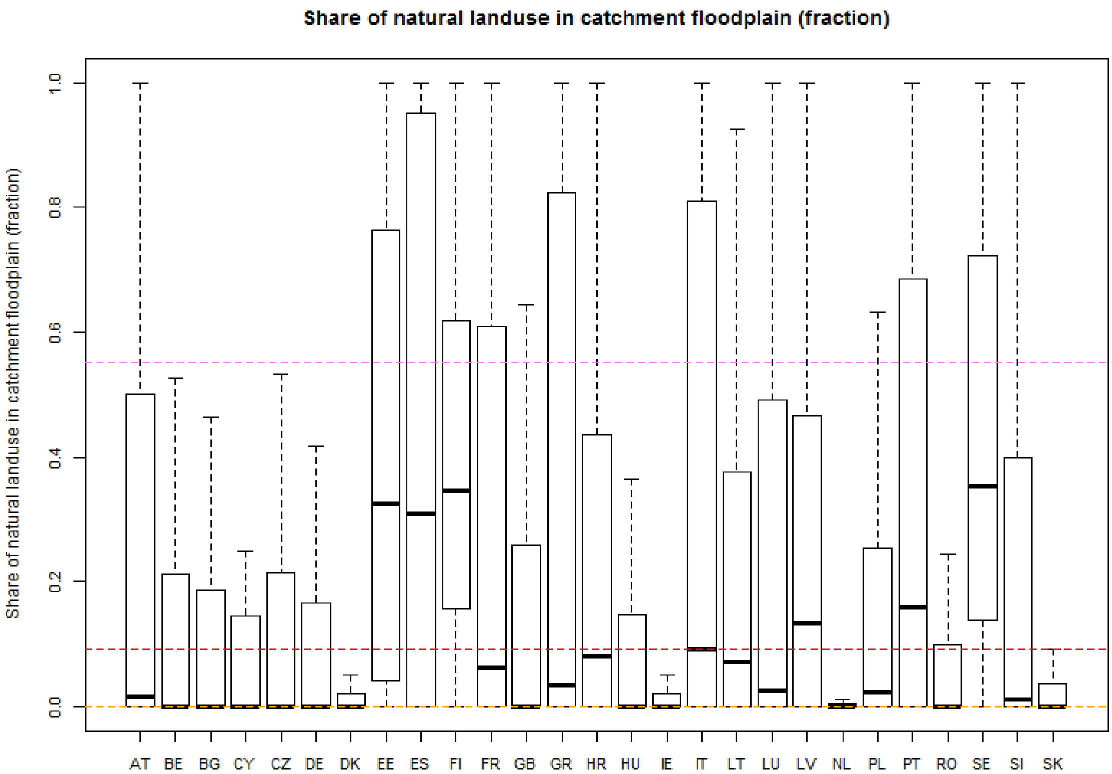


Figure 21 – boxplot of country values of the indicator "ShareNaturalFloodplain" . Horizontal lines: yellow=25th percentile, red=median, pink=75 th percentile of European values.

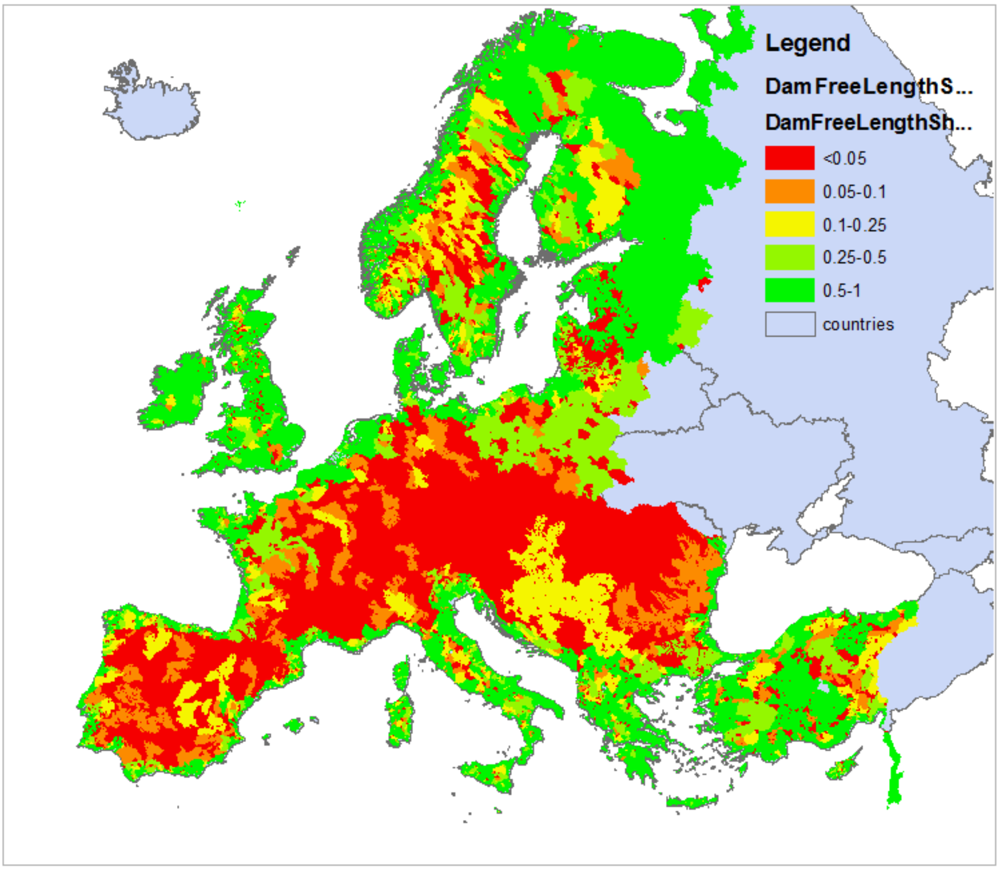


Figure 22 – map of the dam indicator DamFreeLengthShare

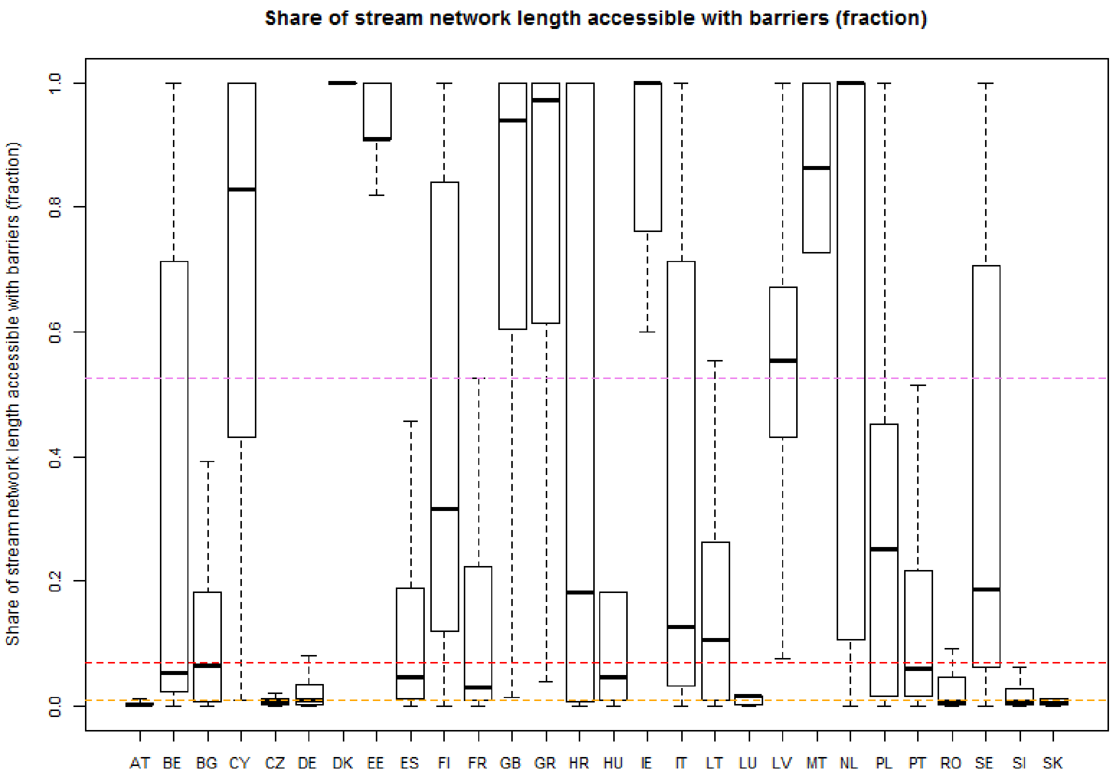


Figure 23 – boxplot of country values of the DamFreeLengthShare indicator. Horizontal lines: yellow=25th percentile, red=median, pink=75th percentile of European values

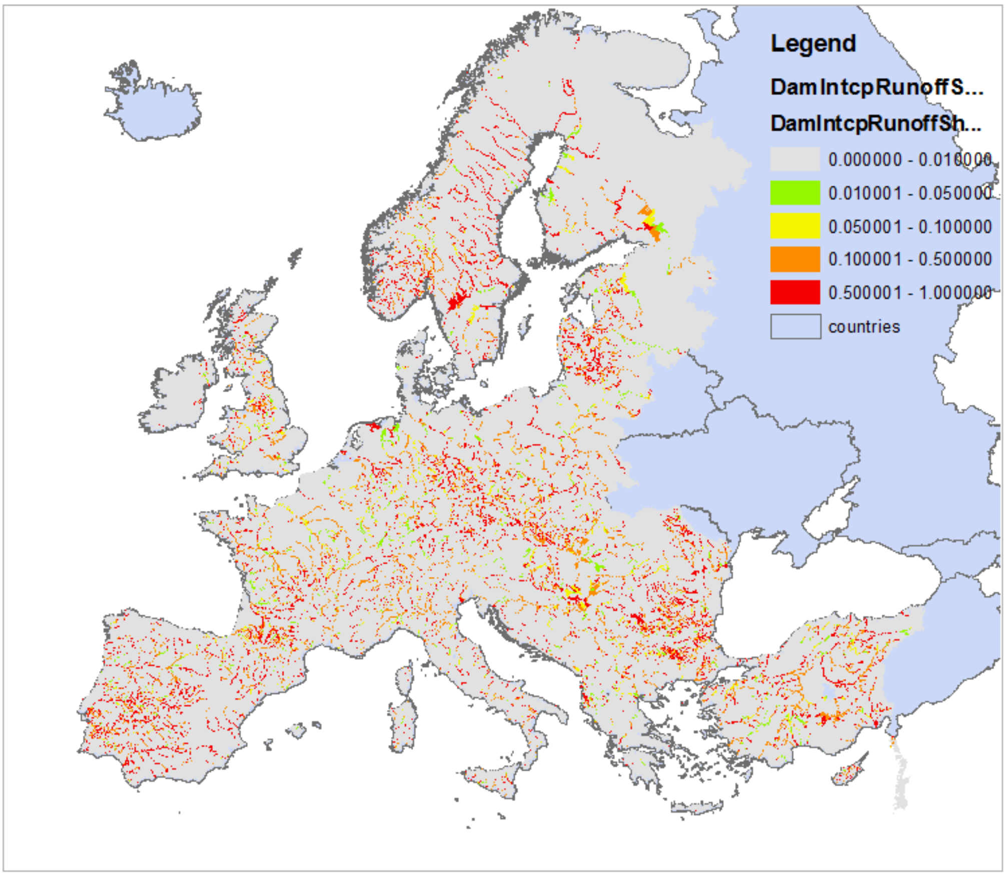


Figure 24 – map of the "DmIntcpRunoffShare" indicator

6. European and national assessments: towards an agreed-upon continental picture of pressures

A harmonized identification and assessment of pressures is a prerequisite of any European scale assessment of the effectiveness of the implementation of the WFD. Despite a well-established assessment framework (e.g. CIS Guidance Document n. 3, 2003[14]), assessments conducted in the different EU member states may not be always fully comparable.

The present report is the third (Part III) of a series of reports on the assessment of the effectiveness of reported Water Framework Directive Programmes of Measures. The concept and rationale of building a set of European scale pressure indicators, to be compared with pressures and impacts reported by Member States, was presented in the first report (Part I, Pistocchi et al., 2015[15]) and further discussed at a workshop held in May 2016 in Ispra, Italy, as outlined the second report (Part II, Pistocchi et al., 2017).

Part I was the first attempt to check the consistency of Reported Percentages of water bodies at Risk of not achieving the WFD goals by 2015 due to each category of pressures (RPRs), with the partial evidence available from European-scale datasets and assessments compiled by the JRC. The analysis did not aim at assessing the accuracy of reporting: it was purely *factual* and *non-judgmental*. It consisted of comparing the ranking of river basin districts (RBDs) from RPRs and European indicators, and identifying the RBDs where the two ranks agree or disagree.

Several reasons for a discrepancy between RPRs and European scale evidence were acknowledged to exist. Part I was made available for comments by EU Member States. Comments were submitted by experts from Austria, Germany, the Netherlands and Portugal. These, on the one side, pointed at topics and areas where the European scale indicators were apparently in contrast with the known conditions in the field, highlighting persisting data and knowledge limitations in the continental picture. On the other side, they raised general concerns for the possibility that an assessment at European scale could create confusion, and sometimes even undermine the assessments made at Country level. Both aspects deserve particular attention: the JRC should validate their indicators at any opportunity, and the interpretation of results should be always considerate of those aspects that cannot emerge from continental scale indicators, but are known to be relevant in a given context.

Building on the feedback concerning Part I, the pressure indicators were revised and discussed with experts from the Member States (Part II). Also the indicators in the current version (Part III) were submitted for a review by experts from the EU Member States during 2017. Experts from some member states have provided comments, which have been taken and addressed as summarized in the following table.

Country	Review Comments	Reaction
Denmark	Concerns for the lack of clarity on which planning cycle (first or second RBMP) has been taken into consideration.	We clarify that indicators do not reflect RBMP scenarios but only what are considered the current conditions.
Finland	The morphological alteration indicators may be difficult to apply in the Finnish	We acknowledge the indicators based on floodplain encroachment

14 https://circabc.europa.eu/sd/a/7e01a7e0-9ccb-4f3d-8cec-aeef1335c2f7/Guidance%20No%203%20-%20pressures%20and%20impacts%20-%20IMPRESS%20(WG%202.1).pdf

15 http://publications.jrc.ec.europa.eu/repository/handle/JRC96943

Country	Review Comments	Reaction
	context, where landforms are not easy to classify as "floodplains". The indicator "DamFreeLength" may be ambiguous as it may correspond both to impacts of barriers on fish migration, and morphological alterations. The database of dams may seems incomplete for Finland.	may not be fully representative of the Finnish and similar contexts. The "DamFreeLength" indicator is meant to represent the interruption of continuity in fish habitat. It is anticipated to suffer from data incompleteness in certain areas. The database of dams is meant to be improved as new data become available.
Germany[16]	Total Nitrogen, share of point sources for Phosphorus and urban runoff indicators tend to show more problems than expected based on monitoring, particularly in the Western (coastal) part of the Land. The DamFreeLength indicator does not seem to be very conclusive.	Specific comments on model performance at given sites are very useful to drive the improvement of the indicators. JRC models are being updated periodically in order to incorporate new pressure and monitoring data made available over time.
Hungary	The geometry of the HE2 (CCM2) hydrography does not always match the real drainage network, which can impact the reliability/representativeness of European scale results. The morphological alteration indicators (DamFreeLength and landcover/infrastructure in floodplains) do not always seem representative for the Hungarian conditions. Water quality as assessed with the GREEN model matches assessments with the Danube MONERIS model only to a limited extent. Part of the discrepancies may be due to the delineation of water bodies and catchments The lack of a sound knowledge of water abstractions may hinder the calculation of hydrological alteration indicators. With the current, limited knowledge of water abstractions, using a daily step hydrological model seems disproportionate.	See comments from Poland on CCM2 hydrography limitations. See comments from Germany and on model accuracy. We acknowledge that information on abstractions is crucial and is apriority for the development of more specifically applicable hydrological alteration indicators. This is a priority for future development.

[16] Comments were provided by experts from Land Schleswig-Holstein, and refer to that specific part of the German territory.

Country	Review Comments	Reaction
Lithuania	The GREEN model results appear to match national assessments (based on monitoring data and the SWAT model) only to a limited extent.	See comments from Germany.
Netherlands	General concerns on the lack of clarity and transparency/reproducibility in the assessment of the indicators. Nitrogen and phosphorus indicators do not account for specific processes in the Netherlands, such as deposition of N due to algal blooms and seepage of P-rich seawater. The Urban runoff indicator appears to overestimate the problem for the Netherlands, by not taking into account the locally large infiltration rate even of urban surfaces, and the fact that most of the urban runoff is collected in combined sewers, or anyway not discharged directly to rivers. The calculation of the Q10 and Q25 indicators highlights unrealistically high values in the South of the country. Moreover, the WEI+ may not capture a situation like the Netherlands, where surface and groundwater are tightly interconnected and a significant share of demand is met with groundwater resources.	We agree the transparency and reproducibility of the indicators is key. While efforts have been made to disclose all relevant information in this version of the indicators, attention on this aspect will be reinforced in future developments. At the same time, the use of models for the calculation of certain indicators requires delving into technicalities that can only find place in more specialized reports or papers. On the local improvement of models, see comments of Germany and others.
Poland	The geometry of the HE2 (CCM2) hydrography does not always match the real drainage network, which can impact the reliability/representativeness of European scale results. As for the nutrient indicators, "other sources" play a significant role in many catchments, suggesting a disaggregation into finer categories may be advisable. The urban runoff indicator for the lower Vistula, and the phosphorus load for the Vistula and Central/Southern Poland seem to overestimate the problem.	The CCM2 hydrography is derived from the digital elevation model and suffers from known inaccuracies on the position of rivers, junctions etc. Moreover, when the drainage network is artificial (e.g. in hydraulically reclaimed plains or highly impacted morphologies) there can be a complete mismatch between the CCM2 network and reality. These mismatches, while locally relevant, are expected to have a relatively minor impact when looking at the regional or coarser scale. Nevertheless, this type of comments is very useful in the interpretation of the results.

Country	Review Comments	Reaction
Romania	Concerns about the use of, and potential confusion arising from, the JRC pressure indicators. These are considered to be generally not comparable with corresponding assessments from the Member States, because they rely on different models and assumptions. Moreover, the JRC indicators are presented with legends and reference thresholds that may differ from those of MS.	We clarify that the JRC indicators do not have to necessarily match with the corresponding assessments of the Member States, but the reasons of possible discrepancies need to be well understood. While legends and reference thresholds used by the JRC do not correspond to, nor are suggestive of classifications of ecological status, and are designed to provide a readable pan-European picture, they should be improved in order to avoid confusion in the interpretation.

Table 5 – comments received from experts in Member States, and JRC reactions

In this report (Part III) we have described the current state of implementation of European scale Water Pressures Indicators showing that many of the main pressures expected to affect the European water bodies can be represented through specific indicators. These require careful verification in order to ensure they are representative of the European picture. However, due to the complexity and variability of conditions across Europe, their accuracy at the local scale will always be relatively low and their pointwise validity may be easily questioned. Therefore, indicators at European scale should not be taken as conclusive assessments for a given watershed or subbasin.

At the same time, the development of an EU-wide system of pressure indicators may trigger some useful developments based on a constructive comparison of European and country- or river basin level assessments.

First of all, a comparison may clarify where and to which extent information reported at European scale is insufficient and should be improved. For instance, certain significant discrepancies between modelled and monitored nutrient concentrations may arise from limited or low-quality data available for model calibration at European scale, compared with what is actually available at local scale. For other topics, such as urban runoff, information at European scale is simply not available, and should be retrieved in ways to be discussed. An element of particular importance is the distribution of water abstractions, driving hydrological alteration and the corresponding impacts. The development of EU-wide models and indicators is an opportunity to check, during model calibration and validation, the quality of reported data. For instance, the calibration of the GREEN model for nutrients has highlighted that the available European nutrient monitoring databases contain a number of inconsistencies and are sometimes significantly incomplete.

Secondly, European maps representing continental trends and hot spots of pressures may highlight differences in reporting among different member states. Developing EU-wide representations may be a nudging tool to stimulate harmonization of the assessments across the continent.

Finally, the current version of the Water Pressure Indicators represents more the beginning of an open process than a conclusive outcome. It is important that they are interpreted and used in the context of an iterative consultation between the European Commission and the Member States' competent authorities and experts, towards co-developing a broadly accepted "big picture" of human pressures on European water bodies, calling for effective management measures in order to achieve the objectives of the Water Framework Directive.

Indicators map viewer

The indicators described in this report can be consulted through a mapping application available at the web site:
http://water.jrc.ec.europa.eu/arcgis/apps/MapSeries/index.html?appid=2b567ef819134086a43739a6fc7acf00 .

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List of abbreviations

HE1 =Hydro-Europe data model and hydrography

HE2 = Hydro-Eurasia data model and hydrography

EEA = European Environment Agency

FDC = flow duration curve

GREEN = geospatial regression equation for European nutrient losses

RBD = River Basin District

WFD = Water Framework Directive 60/2000/EC

CCM2 = Catchment Characterization and modelling v. 2

WEI = water exploitation index

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